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FINAL

HISTORICAL INFORMATION SUMMARY AND PRELIMINARY HEALTH RISK ASSESSMENT

Operable Unit No. 3 - IHSS 200-202

U S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

JUNE 1991

ENVIRONMENTAL RESTORATION PROGRAM

ADMIN RECORD

FINAL

HISTORICAL INFORMATION SUMMARY AND PRELIMINARY HEALTH RISK ASSESSMENT

OPERABLE UNIT NO. 3 - SITES 200-202

U S. DEPARTMENT OF ENERGY
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ENVIRONMENTAL RESTORATION PROGRAM

EXECUTIVE SUMMARY

This report for Individual Hazardous Substance Sites (IHSSs, or Sites) 200 (Great Western Reservoir), 201 (Standley Lake), and 202 (Mower Reservoir) was prepared in response to requirements in the Interagency Agreement (IAG) between the U S Department of Energy (DOE), the U S Environmental Protection Agency (EPA), and the Colorado Department of Health (CDH) The sediments in these reservoirs contain low levels of plutonium as a result of past activities at the Rocky Flats Plant (RFP) The IAG identifies the following primary objectives for this report

1 Submit all known and accumulated data describing, detailing or defining contamination within the reservoir(s) and tributaries of the reservoir(s) including surface and ground water sources, and

2 Submit a health risk assessment documenting the risks derived from all potential exposures associated with a no action alternative for remediation of the contamination

After evaluating over 30 documents containing data relevant to Sites 200-202, it became evident it would be impractical to append the entire body of existing data to this document The IAG data submission requirement is addressed by summarizing pertinent data throughout the report, by including a bibliography listing general references and available documentation of data for Sites 200-202, and by appending specific data sources for the three Sites to the report

The existing data for Sites 200-202 were collected for the purpose of site characterization rather than to support a rigorous quantitative health risk assessment After evaluating the existing data against EPA guidance for data useability in risk assessments it became apparent that the data do not meet current quality control standards necessary to support a quantitative risk assessment As a result, this report includes a qualitative human health risk assessment for Sites 200-202 In addition, a "generic" risk assessment calculation is included which shows the steps and many assumptions underlying a quantitative risk assessment, and which generates risk values based on hypothetical plutonium concentrations in reservoir sediments and water under various exposure scenarios This calculation is useful in helping to determine whether known contamination at the three reservoirs poses an imminent health risk to the public The following discussions provide

a brief summary of the information provided in this report in support of the objectives listed above

Sites 200 (Great Western Reservoir), 201 (Standley Lake), and 202 (Mower Reservoir) comprise three of the four Sites within Operable Unit No 3 (OU 3) OU 3 differs from other RFP OUs in that it is located outside the RFP boundary The three reservoirs are located outside the eastern boundary of the RFP Great Western Reservoir serves as the municipal water supply for the City of Broomfield, while Standley Lake supplies water to the cities of Thornton, Northglenn and Westminster Mower Reservoir is a much smaller, privately-owned impoundment used for agricultural purposes (i e , cattle watering and irrigation)

Past environmental investigations of Sites 200-202 have shown that plutonium concentrations in the bottom sediments of all three reservoirs exceed estimated background (nuclear testing fallout) concentrations The elevated plutonium concentrations are attributed to historical airborne (fugitive dust) and waterborne releases from the RFP These releases resulted primarily from RFP operations in the 1950s, 1960s, and 1970s Pollution control measures implemented at the RFP since this time have effectively eliminated the sources of the plutonium In addition, surface water control measures now allow the RFP to prevent runoff and effluent from the main RFP production facility from reaching the reservoirs

The information presented in this report points to the following conclusions about Sites 200-202

- Plutonium and americium (a decay product of plutonium) are the only known contaminants in the reservoirs attributable to RFP releases This conclusion is based on extensive water quality monitoring data for Great Western Reservoir and Standley Lake and analysis of bottom sediment samples for numerous potential RFP-derived contaminants, including various radionuclides and beryllium

- Plutonium-bearing horizons of bottom sediments in Great Western Reservoir and Standley Lake have been covered by subsequent sedimentation The highest sediment plutonium concentrations were found to exist in the deepest areas of each reservoir The concentrations of plutonium in the sediments in areas of highest exposure potential (i e , near-shore areas) of Great Western Reservoir and Standley Lake are above background levels, as measured by several past studies in sediments of Colorado Front Range reservoirs believed to be unaffected by RFP releases

- Maximum plutonium concentrations measured to date in Great Western Reservoir sediments are several times higher than those measured to date in Standley Lake sediments

- Only four sediment samples have been collected (all in 1970) to assess plutonium concentrations in Mower Reservoir sediments The highest plutonium concentrations measured were roughly twice the estimated background concentration due to atmospheric testing fallout, and were several times lower than the highest concentrations measured to date in Standley Lake

- Plutonium is strongly adsorbed to the clay-rich sediments typical in impoundments near the RFP Studies have shown that plutonium in the reservoir sediment columns is effectively immobilized

- Routine water quality monitoring indicates that water quality in Standley Lake and Great Western Reservoir has not been measurably impacted by plutonium in the reservoir sediments A single water sample collected in 1970 from Mower Reservoir showed background plutonium concentrations (background is due to atmospheric testing fallout)

- Residential tap water derived from Standley Lake and Great Western Reservoir is routinely analyzed for plutonium Results consistently indicate that plutonium concentrations are well below CDH drinking water standards

- Of the many potential exposure pathways identified for the reservoirs, the airborne pathway from reentrainment of exposed sediments is considered the most significant pathway that can convey plutonium to human receptors from Sites 200-202 Airborne plutonium concentrations measured by air monitors downwind of Sites 200-202 have remained well below the 0 02 picocuries per cubic meter (pCi/m^3), or 0 0007 becquerel per cubic meter (Bq/m^3) standard set by DOE All potential exposure pathways, however, will be addressed under scheduled RCRA Facility Investigation/Remedial Investigation (RFI/RI) activities at Sites 200-202

Additional data necessary to support a quantitative risk assessment for Sites 200-202 will be collected during scheduled RFI/RI activities This report will serve as the basis for the RFI/RI scoping process Risk assessment and site characterization needs will be integrated in the RFI/RI to ensure that all potential site contaminants and exposure pathways are identified and characterized to the extent necessary to perform a quantitative human health risk assessment

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LIST OF ACRONYMS AND ABBREVIATIONS

ANL	Argonne National Laboratory
ARARs	Applicable or Relevant and Appropriate Requirements
ATSDR	Agency for Toxic Substances and Disease Registry, U S Public Health Service
BEIR	Biological Effects of Ionizing Radiation
BNA	base neutral acid
Bq	Becquerel
BRA	baseline risk assessment
CDH	Colorado Department of Health
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHWA	Colorado Hazardous Waste Act
Ci	Curie
cm	centimeter (10^2 meters)
CSF	cancer slope factor
CSM	Colorado School of Mines
CSU	Colorado State University
CWQCC	Colorado Water Quality Control Commission
DNA	deoxyribonucleic acid
DOE	U S Department of Energy
dpm	disintegrations per minute
DRCOG	Denver Regional Council of Governments
EPA	U S Environmental Protection Agency
f_1	GI absorption factor
ft	feet
FS	Feasibility Study
g	gram
gal	gallons
GBq	gigabecquerel (10^9 becquerels)
GI	gastrointestinal
HEAST	Health Effects Assessment Summary Tables
hr	hour
IAG	Interagency Agreement
ICRP	International Commission on Radiation Protection
IHSS	Individual Hazardous Substance SITE
in	inch
K_d	distribution coefficient
kg	kilograms (10^3 grams)
km	kilometers (10^3 meters)
K_{ow}	logarithmic octanol-water partition coefficient
LET	linear energy transfer
l	liter
lbs	pound
m	meter
m^1	per meter
mCi	millicurie (10^3 curies)

LIST OF ACRONYMS AND ABBREVIATIONS
(continued)

MeV	million electron volts
mm	millimeter (10^{3} meter)
mph	miles per hour
NAS	National Academy of Sciences
NCP	National Oil and Hazardous Substances Contingency Plan (or National Contingency Plan)
NEPA	National Environmental Policy Act
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
OU	operable unit
pCi	picocurie (10^{12} Curies)
PuO_2	plutonium dioxide
QA	quality assurance
QC	quality control
RAG	Risk Assessment Guide
RCRA	Resource Conservation and Recovery Act
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFP	Rocky Flats Plant
sec	second
TGLD	Task Group on Lung Dynamics
um	micrometer (10^{6} meter)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USGS	United States Geological Survey, U S Department of the Interior
VOC	volatile organic compound
yr	year

LIST OF DEFINITIONS

Completed Exposure Pathway[1] The route a chemical or radionuclide takes from a source to an exposed organism A completed exposure pathway describes a unique mechanism by which an individual or population is exposed to a chemical or radionuclide originating from the site Each completed exposure pathway includes a source, a transport media, a mode of uptake, and a receptor

Data Quality Objectives[1] Qualitative and quantitative statements to ensure that data of known and documented quality are obtained

Data Validation The quality assurance process of reviewing sample collection methods, sample handling and preservation, sample documentation and analytical procedures and results to evaluate the accuracy and reliability of data Data are then classified as being quantitative, qualitative, or unusable

Detection Limit[1] The lowest value that can be reliably detected above the background noise of a given analytical instrument or method

Health Risk Assessment The assessment of chemical or radiological releases from a site and the analysis of public health threats resulting from those releases

Qualitative Risk Assessment An estimate of the likelihood of an adverse health effect by analyzing both exposure and dose response data in a non-numerical manner

Quantitative Risk Assessment Based on completed exposure pathways, probabilities that an individual will develop cancer over a lifetime of exposure are estimated from projected intakes and chemical/radionuclide-specific dose response information

Risk A unitless probability of an individual being affected by an event.

Risk Coefficient For the purposes of this document, a unitless probability of an individual developing cancer from a chronic daily intake of plutonium averaged over 70 years

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[1] Definitions from the EPA Risk Assessment Guidance for Superfund (EPA, 1989)

1.0 INTRODUCTION

This document summarizes available historical information and presents a preliminary human health risk assessment for Individual Hazardous Substance Sites (IHSSs, or Sites) 200 (Great Western Reservoir), 201 (Standley Lake), and 202 (Mower Reservoir) of RFP OU 3 (Off-Site Releases) OU 3 is unique among Rocky Flats operable units in that it is located outside the RFP boundaries These reservoirs have been the subject of numerous environmental studies and monitoring programs aimed at determining the extent to which each has been impacted by releases from the RFP The RFP is owned by the DOE and contractor-operated by EG&G Rocky Flats, Inc as a nuclear weapons research, development and production complex The RFP is situated on 6,550 acres (2,650 hectares) of federal property 16 miles (mi) (26 kilometers[km]) northwest of downtown Denver, Colorado (Figure 1-1)

In addition to the three reservoirs, OU 3 also includes site 199 (Contamination of the Land's Surface) site 199 is the subject of a Past Remedy Report which was submitted to EPA and CDH on April 2, 1991 (DOE, 1991a)

1 1 PURPOSE AND OBJECTIVES

The purpose and objectives of this report are derived primarily from the IAG between the CDH, the EPA, and the DOE (EPA, 1991) The following reporting requirements are set forth in Table 5 of the IAG Statement of Work for each of the three reservoirs

1 Submit all known and accumulated data describing, detailing or defining contamination within the reservoir and tributaries of the reservoir including surface and groundwater sources

2 Submit a health risk assessment documenting the risks derived from all potential exposures associated with a no action alternative for remediation of the contamination

After evaluating over 30 documents containing data relevant to Sites 200-202, it became evident that it would be impractical to append the entire body of existing data to this document The IAG data submission requirement is therefore addressed by summarizing pertinent data throughout the report, by including a bibliography listing available documentation of data for

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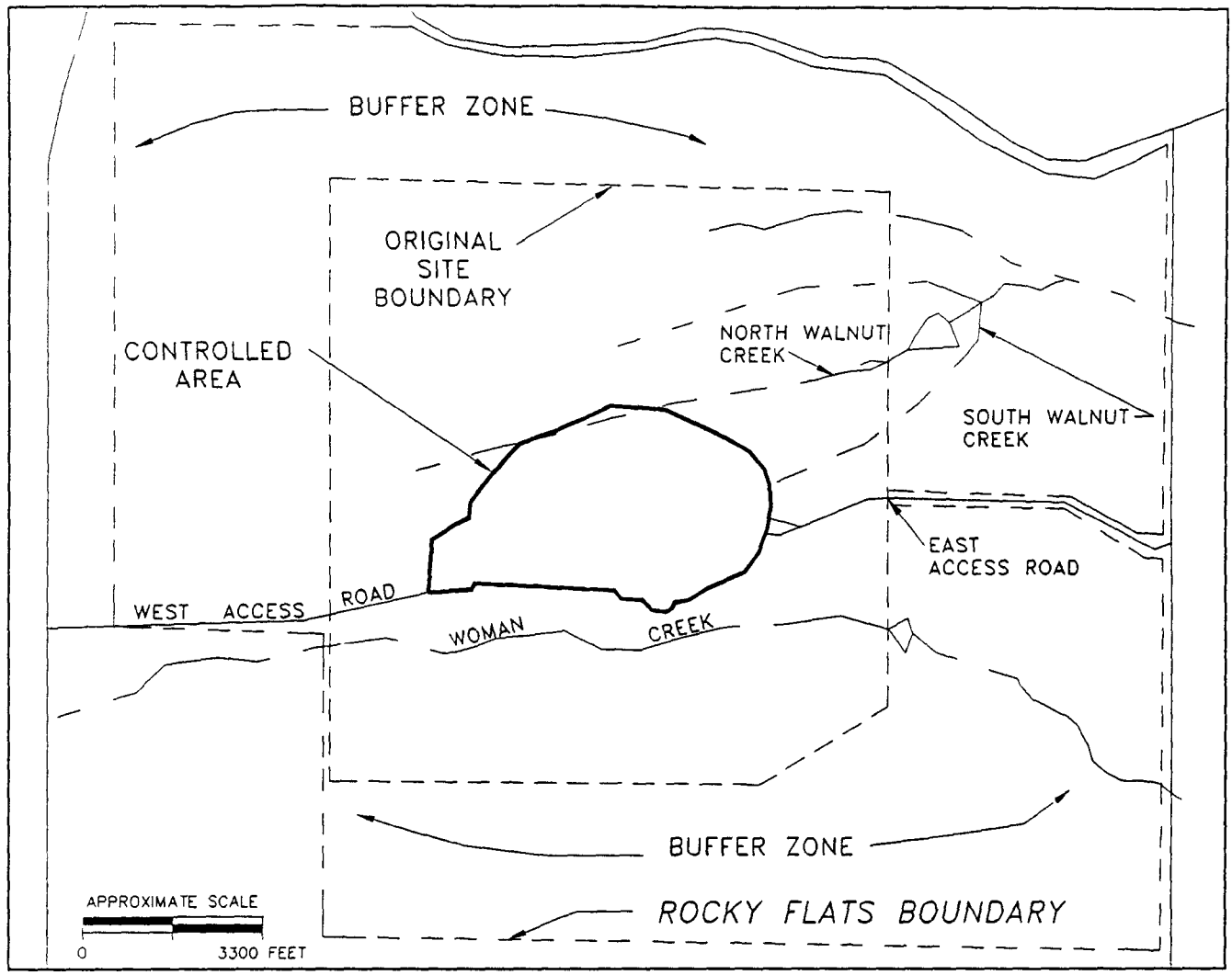

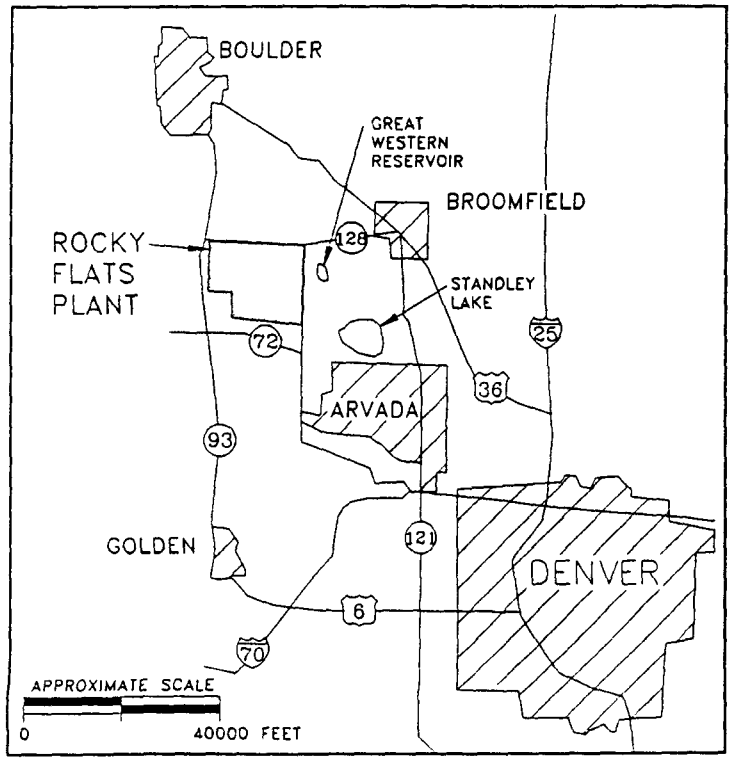

Figure 1-1
ROCKY FLATS LOCATION MAP

ADAPTED FROM FIG 1-1 E G & G DRAFT GEOLOGIC CHARACTERIZATION REPORT JAN 3 1990

Sites 200-202 (Section 6 0), and by providing selected data source documents for the three reservoirs in Appendix D

Section VII D of the IAG Statement of Work details the components of the health risk assessments required for the reservoirs These components are the basis of a rigorous, quantitative assessment of the human health risks associated with contamination at the site, and it is the intent of the IAG that they be applied to Sites 200-202 to assess public health risk under a no action remediation alternative Critical to the performance of such a health risk assessment are the quality and specificity of the data used to support the assessment The EPA's "Guidance for Data Useability in Risk Assessment" document (EPA, 1990a) establishes guidelines for the minimum level of data quality control required to perform a defensible, quantitative risk assessment Virtually all of the available data for Sites 200-202 have been collected for the purpose of site characterization rather than risk assessment While these data are well suited for site characterization, a detailed evaluation against EPA useability criteria (Appendix A) indicates that existing data from Sites 200-202 do not meet current quality control standards to support a quantitative risk assessment This report therefore provides a qualitative risk assessment in which human health risk is defined in relative terms rather than calculated risk values Also included is a "generic" risk assessment calculation (Appendix C) which shows the steps and the many assumptions underlying a quantitative risk assessment, and which generates risk values based upon hypothetical plutonium concentrations in sediment and water under various exposure scenarios This calculation is useful in helping to determine whether known contamination at Sites 200-202 poses an imminent health risk to the public Additional data needed to support a quantitative risk assessment for Sites 200-202 are identified in Section 4 10, these data will be collected under scheduled RFI/RI activities at OU 3

The following specific objectives for this report are based upon the IAG reporting requirements for the reservoirs and the preceding discussion on data useability

- Describe reservoir site physical and chemical characteristics
- Provide a synopsis of environmental studies conducted to date at the reservoirs
- Formulate a conceptual model for contaminant fate and transport from the reservoirs

- Cite evidence to support or invalidate the conceptual model for each reservoir
- Provide a preliminary health risk assessment for the reservoirs, focusing on a no-action alternative
- Identify additional data needed to support a quantitative risk assessment for each reservoir

1 2 REGULATORY BACKGROUND

The IAG groups IHSSs (Sites) at the RFP into 16 Operable Units (OUs), one of which is OU 3 The OU numbering system reflects the relative order of priority for the OUs OU 3 formerly was designated OU 10 The present RFP OU system has emerged from public comment and redevelopment of the IAG, which increased the number of OUs from 10 to 16 and changed their relative order of priority

The primary source for the scope of work for investigation and remediation of RFP OUs is the IAG, which specifies an approach tailored to the particular requirements of the RFP As stated in paragraph 256 of the IAG, all response activities by the DOE under the IAG are to be performed " in accordance with the requirements of all applicable federal and state laws and regulations " These include the applicable requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Contingency Plan (NCP), the Resource Conservation and Recovery Act (RCRA), the Colorado Hazardous Waste Act (CHWA), and pertinent EPA guidance documents Investigation of the RFP OUs is scoped in the IAG per EPA RCRA and CERCLA guidance, which specify collection of data under an RFI/RI to support a site characterization, a health risk assessment, and an environmental evaluation For Sites 200-202, however, the IAG specifies the use of existing data to develop a health risk assessment and does not require an environmental evaluation This document, which summarizes existing site information and assesses human health risk under current site conditions, is typical or a preliminary site assessment developed in a work plan to focus site investigation activities

Great Western Reservoir is used as part of the municipal water supply for the City of Broomfield, while Standley Lake provides water for the cities of Westminster, Thornton and Northglenn

compliance with Federal and state water quality standards applicable to drinking water supply sources is monitored at these reservoirs through routine sampling and analysis Local governments participate in public review of RFP plans and proposals as part of their involvement in decisions about RFP activities which may impact Great Western Reservoir or Standley Lake Mower Reservoir is a much smaller, privately owned impoundment used for agricultural purposes (i e , cattle and irrigation) Although not actively monitored, Mower Reservoir water quality is governed by CDH water quality classification and standards for the South Platte River basin (CDH, 1990a)

1 3 REPORT ORGANIZATION

The remainder of this report is organized into the following sections

- Section 2 0 provides a discussion of site characteristics and history, and summarizes environmental studies conducted to date at Sites 200, 201, and 202
- Section 3 0 provides a description of the site conceptual model used in the preliminary human health risk assessment
- Section 4 0 provides a preliminary human health risk assessment, including identification of data needed to conduct a quantitative human health risk assessment
- Section 5 0 provides conclusions and recommendations
- Section 6 0 provides a bibliography and references
- Appendix A provides an evaluation of existing reservoir data useability for risk assessment against EPA criteria
- Appendix B provides general guidelines for development of a health risk assessment
- Appendix C provides a "generic" risk assessment calculation for Sites 200-202
- Appendix D provides selected data source documents for Sites 200-202

2.0 SITE BACKGROUND AND DESCRIPTION

The RFP fabricates metal components for nuclear weapons from plutonium, uranium, beryllium, and stainless steel Support activities include chemical recovery and purification of recyclable transuranic radionuclides, and research and development in metallurgy, machining, nondestructive testing, coatings, remote engineering, chemistry, and physics These operation generate nonhazardous, hazardous, radioactive, and mixed radioactive waste streams (DOE, 1987) The 385 acre (156 hectare) main production facility of the RFP, within the controlled area, is surrounded by a 6,150 acre (2,491 hectare) buffer zone which delineates the RFP boundary (Figure 1-1)

The three OU 3 reservoirs are located outside the eastern boundary of the RFP (Figure 2-1), two to four mi (3 2 to 6 4 km), from the main production facility The locations are downgradient and generally downwind of the RFP Each of the reservoirs has received some of its influent water from drainages flowing from the RFP during the operating history of the plant A system of diversion ditches and retention ponds within the RFP now allows the RFP to prevent surface water from the main production facility from reaching any of the reservoirs (Figures 2-2 and 2-3) Great Western Reservoir is isolated completely from RFP surface water by a ditch which diverts flow around the reservoir (Figure 2-3) Plans are proceeding for construction of a similar diversion around Standley Lake Extensive environmental monitoring of ground water, surface water, ambient air, and soils on and near the RFP is conducted by a number of agencies and municipalities (Section 2 1 3 3 and 2 2 2 2) While it is possible that the reservoirs could be affected by future airborne and/or waterborne emissions from the RFP, it is expected that any such emissions would be detected and characterized by environmental monitoring, and that the potential impact of the resulting contamination on the reservoirs could be readily assessed The contamination of Sites 200-202 described in this report is a result of both routine operational procedures and accidental releases during the first several decades of the RFP operation (early 1950s to late 1970s) Environmental monitoring results summarized in monthly and annual reports (Dow, 1971-1989, CDH, 1970-date) suggest that environmental control measures and changes in operating procedures have effectively prevented additional radioactive contaminants from impacting the reservoirs

Numerous investigators (see Sections 2 1 3 and 2 2 2) have studied the impacts of RFP contaminants on the sediments, water, and ecosystems of Great Western Reservoir, Standley Lake, and their tributary drainages from the RFP (Walnut Creek and Woman Creek, respectively) Almost all of this work has focused on radionuclides, primarily plutonium and americium, which is a decay product of plutonium Although concentrations of nonradioactive contaminants are routinely measured in reservoir and drainage water and have been detected in upstream holding ponds and drainages on the RFP, virtually no data exist for prospective RFP-derived nonradioactive contaminants in the reservoir sediments Prospective radioactive and nonradioactive contaminants in the reservoirs will be fully characterized under scheduled RFI/RI activities at Sites 200-202

2 1 GREAT WESTERN RESERVOIR (Site 200)

Site 200 encompasses Great Western Reservoir, off-site reaches of Walnut Creek (which formerly flowed into the reservoir from the RFP), and downstream surface water features possibly impacted by outflow from the reservoir (Figure 2-1) Portions of Walnut Creek within the boundaries of the RFP will be investigated as RFP OU 6 and are not included in Site 200

2 1 1 Location and Description

Great Western Reservoir is located approximately 1 5 mi (2 4 km) east of the RFP's eastern boundary in Sections 6 and 7 of Township 2 South, Range 69 West (T2S, R69W) (Figure 2-1) The reservoir is owned by the City of Broomfield and is utilized solely for the city's municipal water supply Public access to Great Western Reservoir and the surrounding area is fenced and posted to exclude public access (Broomfield, 1990)

Pre-construction information for the Great Western Reservoir site is not given in available references The original reservoir was built in 1904 as a irrigation water supply The dam has been enlarged on several occasions, most recently in 1958 The maximum height of the dam is 69 feet (ft) (21 meters [m]) (Hydro-Triad, 1981) The present reservoir volume is 3,250 acre-feet (401 hectare-meters) The bottom and sides of the reservoir are unlined, meaning that the reservoir may be hydraulically connected to the ground water system in the area (Miller, 1990)

2 1 2 Site Conditions

Although little site-specific information is available concerning the geology and ground water hydrology of Site 200, plant-wide hydrogeologic studies give an indication of conditions in the vicinity of the RFP The following sections summarize relevant results of these studies and provide site-specific information where available

2 1 2 1 Geology and Ground Water Hydrology

The U S Army Corps of Engineers utilized data from two existing boreholes near Great Western Reservoir as part of a 1989 evaluation for a surface water interceptor system for the reservoir In these boreholes, alluvium surficial deposits are underlain by Arapahoe Formation bedrock at depths of 5 and 16 ft (1 5 and 4 9 m) Bedrock consists of interbedded sandstone, siltstone and claystone and dips slightly to the east (Corps of Engineers, 1989) The precise locations of these boreholes are not given in this document The Arapahoe Formation averages 250 ft (76 m) in thickness in the RFP area, and is underlain by several hundred feet (approximately 100 m) of shale comprising the upper portion of the Laramie Formation (USGS, 1976) It is expected that a similar stratigraphic sequence underlies Great Western Reservoir

Two hydraulically-connected ground water systems occur at the RFP An unconfined system which is present in saturated surficial deposits (the upper hydrostratigraphic unit) in many areas of the RFP, and a confined system in sandstones and claystones of the underlying Arapahoe Formation (the lower hydrostratigraphic unit) (USGS, 1976) The shallow unconfined system is recharged by infiltration from incident precipitation and from surface and baseflow water (e g , drainages and reservoirs) Ground water flow is generally to the east and towards drainages Ground water locally discharges as seeps or springs in drainages, especially where the surficial deposit/bedrock contact is exposed Large water table fluctuations may occur in the shallow system in response to seasonal variations in recharge and discharge, with the highest water levels generally occurring during the months of May and June and the lowest water levels generally occurring in January and February As a result of these fluctuations the lateral and vertical extent of saturated surficial deposits varies seasonally Several past studies have measured hydraulic conductivity in the upper and lower hydrostratigraphic units using drawdown-recovery tests, pump tests, packer testing and slug testing on selected wells (USGS, 1976, Hydro-Search, 1985,

Rockwell, 1988a) Recent work has estimated hydraulic conductivities for RFP geologic units at 10^{-5} cm/sec in the Rocky Flats Alluvium, 10^{-5} cm/sec in subcropping Arapahoe Formation sandstones, 10^{-6} cm/sec in unweathered Arapahoe Formation sandstones, and 10^{-7} cm/sec in both weathered and unweathered Arapahoe Formation claystones (EG&G, in press)

Confined ground water in the lower hydrostratigraphic unit occurs primarily in lenticular sandstone bodies within claystone Ground water flow in the upper hydrologic unit occurs in the unconsolidated Quaternary surficial deposits and the shallow sandstone within the bedrock Recharge to this unit occurs from infiltration from streams and precipitation The lower hydrologic unit is found in the deeper bedrock sandstones which exhibit confined conditions Recharge to this unit occur primarily from baseflow and leakage from the overlying claystone Ground water in the lower hydrologic unit flows east towards a regional discharge area along the South Platte River, some 20 mi (32 km) east of the RFP Local seeps occur along the sides of drainages where the bedrock crops out Calculated horizontal linear flow velocities for the system average 0 1 ft/day (0 03 m/day) in the sandstones and approximately $9x10^{-4}$ ft/day ($2.7x10^{-4}$ m/day) in the claystone A relatively steep downward gradient is also observed in areas of the formation The effects on ground water movement by faulting in the lower hydrologic unit are not known (USGS, 1976, Hydro-Search, 1985)

Specific hydrogeologic information for Great Western Reservoir is limited to drilling records from privately-owned water wells in the vicinity of the reservoir Drilling and filing records held by the Colorado Division of Water Resources suggest that surficial deposits near the reservoir range in thickness from 15 to 50 ft (4 6 to 15 m) and average approximately 25 ft (7 6 m) thick These deposits typically are described as clay, sandy clay, or clay with gravel and boulders, locally capped by five to six feet of topsoil The underlying bedrock is described in most well records as alternating layers of shale and sandstone, which is assumed to be a very generalized description of the Arapahoe Formation Most of the wells for which records were examined were completed in sandstones at depths ranging from 35 to 275 ft (10 7 to 84 m) Static water levels averaged 10 to 50 ft (3 to 15 m) higher than the screened interval, indicating moderate pressure head in the sandstones

2 1 2 2 Surface Water

Great Western Reservoir is fed primarily by Clear Creek via Lower Church Ditch (Figure 2-1) Until recently, the reservoir also received influent from the north and south branches of Walnut Creek, both of which flow from the RFP The two branches merge into a single drainage within the RFP boundary (Figure 2-2) A chromic acid release at the RFP in 1989 prompted construction of a Walnut Creek diversion, known as the Broomfield Diversion Ditch (Figure 2-3) Surface water affected by the chromic acid was diverted around Great Western Reservoir and did not impact the reservoir (Dow et al , 1971-1989) Walnut Creek flow from the RFP is now treated and diverted south around Great Western Reservoir into the drainage below the reservoir outlet, where it combines with outflow from the reservoir The Broomfield Diversion Ditch effectively prevents surface water from the RFP from reaching Great Western Reservoir Walnut Creek continues below Great Western Reservoir and eventually discharges into Big Dry Creek several miles downstream from the reservoir (USGS, 1980)

Within the RFP boundary, the North and South Walnut Creek drainages contain the A and B-series holding ponds, respectively In North Walnut Creek, there are four ponds designated A-1, A-2, A-3 and A-4, from west to east (Figures 2-1 and 2-2) Ponds A-1 and A-2 are used only for spill control, and North Walnut Creek stream flow is diverted around them through an underground pipe Pond A-3 receives North Walnut Creek stream flow and runoff from the northern portion of the RFP Pond A-4 is utilized for surface water control and for overflow from Pond A-3 (Rockwell, 1988a)

Five retention ponds located along South Walnut Creek are designated B-1, B-2, B-3, B-4 and B-5, from west to east (Figures 2-1 and 2-2) Ponds B-1 and B-2 are reserved for spill control Pond B-3 receives treated effluent from the RFP sanitary sewage treatment plant Ponds B-4 and B-5 receive surface runoff from the central part of the plant and routinely receive discharge from Pond B-3 Pond B-5 also collects overflow from Pond B-4 (Rockwell, 1988a)

2 1 3 Environmental Investigations

From the opening of the RFP in 1952 through approximately 1979, water containing decontaminated process and laundry effluent was discharged through the B-series ponds to South

Walnut Creek (Rockwell, 1988a, Dow, 1973) Cooling tower blowdown and treatment system steam condensate were discharged to the A-series ponds, which feed into North Walnut Creek These discharges contained radionuclides which accumulated in the sediments of the holding ponds, Walnut Creek, and Great Western Reservoir (DOE, 1980) The EPA concluded in 1975 that historic releases of contaminants from the RFP to Great Western Reservoir resulted primarily from the following activities (Appendix D, Document D-3)

- Early operational practices at the plant (1950s and 1960s)
- Reconstruction of the holding ponds between 1970-1973, which resuspended pond sediments and released some of this material to Great Western Reservoir
- A 1973 tritium release from the RFP (Section 2 1 3 2)
- Airborne transfer of radionuclides (primarily plutonium)

The following sections present chronological summaries of environmental studies conducted to date of Site 200 Analytical results from these studies are summarized in Table 2 1 The studies are incorporated by reference to the documents in Appendix D and to the bibliography in Section 6 0

2 1 3 1 Reservoir and Drainage Sediments

The EPA conducted the first extensive sampling of bottom sediments in Great Western Reservoir in February and September 1970 The results indicated that a layer of sediment containing plutonium above the EPA estimated baseline (worldwide atmospheric fallout) level of $\leq$0 1 picocurie per gram (pCi/g), or 0 0037 becquerel per gram (Bq/g) was present in the bottom of the reservoir The thickness of the plutonium-bearing sediments was 2 in (5 cm) or more at all sampling locations The highest concentrations of plutonium were detected in sediments in the Walnut Creek inlet area and the central section of the reservoir (leading to the dam inlet) The lowest concentrations were found in the south arm, the shoreline area between the south arm and the dam, and the western portion of the north arm (Appendix D, Documents D-1 and D-2)

TABLE 2.1

GREAT WESTERN RESERVOIR PLUTONIUM ANALYTICAL DATA

Data Source	Range (pCi/g or l)	Average (pCi/g or l)	Number of Data Points
"Radioactivity Levels in the Environs of the Rocky Flats Plutonium Plant, Golden, Colorado, 1970," April 1971, by EPA (Appendix D, Document D-1)	Surf Sed[1] 0 10-0 13 Water 0 03	0 11 0 03	3 1
"Radioactivity Levels in the Environs of the Rocky Flats Plutonium Plant, Colorado, 1970, Part II," December 1973, by EPA (Appendix D, Document D-2)	Surf Sed. 0 08-0 86 Sed Core 0 03-1 0 Water <0 02	0 34 0 24 <0 02	20 12 1
"Plutonium Levels in the Sediment of Area Impoundments Environs of the Rocky Flats Plutonium Plant - Colorado," February 1975, by EPA (Appendix D, Document D-3)	Surf Sed. <0 06-4 1 Sed Core <0 02-4 5	1 4 0 97	20 15
"Survey of Reservoir Sediments," August 1974, by Dow Chemical (Appendix D, Document D-4)[2]	Surf Sed 0 68-7 9 Sed Core 0 001-5 3	3 4 0 42	5 13
"Radionuclide Concentrations in Reservoirs, Streams and Domestic Waters Near the Rocky Flats Installation," April 1981, by Battelle PNL (Appendix D, Document D-5)[3]	Sed Core 0 01-8 2	2 7	7
"Great Western Reservoir Spillway Sediment Sampling Program Phase I Report," May 1979, by Rockwell International (Appendix D, Document D-7)[4]	Surf Sed. 0 013-0 083 Sed Core 0 007-0 192	0 04 0 074	14 14
"Great Western Reservoir Spillway Sediment Sampling Program Phase II Report," August 1980, by Rockwell International (Appendix D, Document D-8)[4]	Sed Core 0 006-0 07	0 04	7
"Great Western Reservoir Sediment Cores," February 1985, by Rockwell International (Appendix D, Document D-9)	Surf Sed 0 2-6 1 Sed Core 0 013-5 4	3 5 1 2	48 4

[1] Surface sediment grab sample--typically represents upper 5 cm of sediments

[2] Results are for samples collected in 1973 by EPA and split with DOE Surface sediment grabs analyzed by Rocky Flats laboratory, sediment cores analyzed by Battelle Pacific Northwest Laboratory and Lawrence Livermore National Laboratory

[3] Collected numerous water and sediment samples in which plutonium concentrations were not measured

[4] Great Western Reservoir spillway sediments, sampled prior to removal and disposal

EPA resumed their investigation of plutonium in surface water sediments east of the RFP in September 1973 This phase of the study further documented plutonium concentrations in Great Western Reservoir Sediment samples collected both by dredging and coring indicated that plutonium above expected baseline concentrations was present over almost the entire bottom of Great Western Reservoir as a result of releases from the RFP The maximum plutonium concentration detected was 4 5 pCi/g (Table 2 1) The results confirmed the areal distribution of plutonium delineated by the 1970 study, except that the highest concentrations were found in the deepest areas of the reservoir rather than in the Walnut Creek inlet area It was also observed that plutonium-239 concentrations in the uppermost sediment layer increased substantially in the three years between the studies This increase was traced to an influx of sediment resuspended from the RFP holding ponds during pond reconstruction activities This study also measured concentrations in Great Western Reservoir sediments of selected radionuclides other than plutonium and of beryllium No significant variations in the concentrations of these potential RFP contaminants were observed throughout the reservoir or between Great Western Reservoir and Standley Lake (Site 201) (Appendix D, Document D-3)

The 1970 and 1973 EPA studies also sought to confirm the estimated plutonium baseline (background) level by sampling sediments from Front Range reservoirs believed to be unaffected by the RFP During the 1970 study, sediment samples were collected from Calkins Lake and Autrey Reservoir (Appendix D, Documents D-1 and D-2) During the 1973 study, samples were collected from Cherry Creek Reservoir, Marston Lake, and Ralston Reservoir (Appendix D, Document D-3) With one exception, analysis of samples from these reservoirs yielded plutonium-239 levels below $\leq$0 1 pCi/g (0 0037 Bq/g), substantiating EPA's estimated baseline concentration

An accidental release of tritium from the RFP into Walnut Creek and Great Western Reservoir occurred in 1973 (EPA, 1974) Subsequent studies measured tritium concentrations in reservoir water as a result of the release, however, tritium contamination in reservoir sediments has not been studied (Rockwell, 1988b)

In 1974, Battelle Pacific Northwest Laboratories conducted an investigation of radionuclide concentrations in reservoir and stream sediments near the RFP Concentrations of plutonium-239, plutonium-240 and americium-241 in the sediments of Great Western Reservoir and Walnut Creek were found to exceed "baseline levels" (presumably the EPA baseline of $\leq$0 1 pCi/g [0 0037 Bq/g]) The study estimated the total inventories of plutonium and americium in Great Western Reservoir sediments at 244 millicurie (mCi) and 73 mCi (9 02 and 2 7 gigabecquerel [GBq]), respectively Concentrations of cesium-137 were at or below expected baseline concentrations Age-dated sediment cores collected during this study from Great Western Reservoir demonstrated two separate periods of plutonium deposition, 1968-1969 and 1959-1964, both of which coincide with recorded, controlled waterborne releases from the RFP Worldwide fallout from atmospheric nuclear weapons testing may also have contributed to the plutonium in the 1968-1969 sediment layer (Appendix D, Document D-5) The 1968-1969 peak detected in the Battelle study also corresponds to a period of windborne releases from the 903 Pad, a former drum storage area near the eastern end of the RFP controlled area (Figure 2-1) (DOE, 1991a)

Also in 1974, Colorado State University (CSU) conducted a study of plutonium in aquatic systems of the RFP environs This study concluded that the clay fraction of RFP sediments has an extremely high affinity for plutonium and, left undisturbed, provides an excellent retention mechanism for plutonium in the aquatic system Laboratory studies related to this investigation showed that the adsorption of plutonium onto the sediments was rapid and essentially irreversible (CSU, 1974)

Results of studies conducted through 1974 were summarized in a 1975 report by Dow Chemical According to this report, the studies demonstrated that plutonium in surface water impoundments is not readily transported from the impoundments Consequently, the majority of the plutonium released through RFP surface waters was contained in the on-site holding ponds Plutonium concentrations in Walnut Creek sediments increased downstream, suggesting downstream migration of plutonium released at an earlier time (Dow, 1975)

In 1979 and 1980, Rockwell International measured plutonium and americium concentrations in sediments on the Great Western Reservoir overflow spillway prior to removal and disposal of the

sediments by the City of Broomfield Levels of plutonium-239, plutonium-240 and americium-241 in spillway sediment samples were near regional atmospheric fallout background concentrations Plutonium concentrations averaged 0 04 pCi/g and peaked at 0 19 pCi/g in the spillway sediments Plutonium and americium concentrations in the spillway sediments varied little with depth, supporting the conclusion that the sediments accumulated through a combination of hillslope erosion, wave action and sediment mixing, rather than the continuous lacustrine deposition typical of the reservoir bottom sediments (Appendix D, Documents D-7 and D-8)

In 1983, Rockwell International collected 48 sediment surface grab samples and four sediment cores during an extensive Great Western Reservoir geochemical sampling project Duplicates cores were collected at three locations for joint analysis by the City of Broomfield The results of this study were not published in report form, but were summarized in public meetings Maximum recorded plutonium concentrations in these cores were 5 4 pCi/g (Rockwell) and 4 9 pCi/g (Broomfield), occurring at depths of 17 in (43 cm) and 7 5 in (19 cm), respectively The study indicated that plutonium occurred in a discrete sediment horizon corresponding with historical releases from the RFP, and that this horizon had been buried to varying depths by subsequent sedimentation Sedimentation rates based on core samples were determined to vary from >1 4 in/yr (>3 5 cm/yr) in the eastern, deeper areas of the reservoir to <0 1 in/yr (<0 25 cm/yr) in the shallower areas (Appendix D, Document D-9) It was also concluded that no evidence existed of plutonium migration through the sediment column (Rockwell, 1988b)

Numerous studies have focused on surface soil plutonium contamination east of the RFP (DOE, 1991a) Elevated plutonium concentrations have been measured in surface soils north, west, and south of Great Western Reservoir as a result of windborne releases from the 903 Pad, a former drum storage area within the RFP (Figure 2-1) The distribution of surface soil plutonium contamination around the reservoir suggests that windborne particulates have contributed to the plutonium in Great Western Reservoir sediments

2 1 3 2 Reservoir and Drainage Water Quality

Surface water quality in North and South Walnut Creeks and in Great Western Reservoir has been monitored since shortly after the RFP opened in 1951 (Rockwell, 1988a) Tap water is also monitored for prospective RFP-derived contaminants in a number of municipalities around the RFP, including the City of Broomfield, which is supplied by Great Western Reservoir In addition, a number of historical studies have focused on potential impacts to Site 200 water quality as a result of RFP releases

Historical Studies

A 1973 EPA study concluded that dissolved plutonium concentrations in water samples from Great Western Reservoir and Walnut Creek were less than atmospheric fallout-derived baseline concentrations of <0 03 picocuries per liter (pCi/l) (<0 001 Bq/l) Dissolved uranium concentrations were less than the expected natural background of 2 5 micrograms per liter (Appendix D, Document D-3)

An accidental release of tritium in 1973 from the RFP into Walnut Creek and Great Western Reservoir was the focus of another EPA study EPA estimated that the release resulted in a total committed dose of 4 millirem (0 04 millisievert) to the average individual using the reservoir as a source of drinking water EPA found that this dose had minimal impact on public health and did not recommend any mitigative actions (EPA, 1974) Tritium concentrations in Great Western Reservoir waters returned to approximately background levels by 1977 (Rockwell, 1988a) Tritium is one of the radionuclides routinely monitored in RFP surface water effluents and nearby public water supplies (Dow et al , 1971-1989)

In 1974, Battelle conducted an investigation of radionuclide concentrations in reservoirs, streams and domestic tap waters near the RFP Plutonium-239, plutonium-240, and americium-241 concentrations in Great Western Reservoir and Walnut Creek water were slightly above the expected atmospheric fallout background, which was not specifically quantified in this study Concentrations of these three radionuclides in Broomfield tap water were slightly above the detection limit of $4\ 5 \times 10^{-4}$ pCi/l ($1\ 7 \times 10^{-5}$ Bq/l) but were orders of magnitude lower than the EPA

National Primary Drinking Water Regulation of 15 pCi/l (0 55 Bq/l) for total long-lived alpha activity (exclusive of radon and uranium) (Appendix D, Document D-5)

A 1981 Rockwell International study statistically compared available gross alpha and plutonium monitoring data for Great Western Reservoir water and Broomfield tap water with plutonium and gross alpha data for other regional water bodies and supplies All of the comparisons (with the exception of those for Ralston Reservoir water, in which very low plutonium concentrations occurred) indicated that concentrations of plutonium and gross alpha in the regional waters did not statistically differ from those in Great Western Reservoir water and Broomfield tap water (Rockwell, 1981)

Water from Great Western Reservoir is filtered at the Broomfield water treatment plant The filters are routinely backwashed into a settling lagoon at the plant Accumulated backwash sludge is periodically removed from the lagoon and analyzed for a variety of parameters, including plutonium, prior to disposal Plutonium above background concentrations has not been detected in the sludge in past analyses Filter sludge was last analyzed and removed from the lagoon approximately five years ago (Broomfield, 1990) Filter sludge was also analyzed at the Broomfield plant by the EPA (Appendix D, Document D-1) and Battelle (Appendix D, Document D-5)

Routine Monitoring

Routine monitoring of surface water within and around the RFP, of all effluent streams leaving the RFP, and of tap water in municipalities around the RFP has been conducted since shortly after the RFP opened in 1951 Specific sampling and analytical protocols have varied throughout the history of the surface water monitoring program Information regarding sample locations, analytical protocols, analytical results, and compliance with applicable state and federal water quality standards has been summarized since 1971 in the RFP monthly and annual environmental monitoring reports (Dow et al , 1971-1989) The surface water monitoring program is also summarized in the RFP environmental impact statement (DOE, 1980)

Water quality in Great Western Reservoir and off-site reaches of Walnut Creek is routinely monitored by the City of Broomfield and CDH Broomfield samples Walnut Creek at a location immediately east of the RFP on a monthly basis and tests for eight volatile organic compounds (VOCs) An automatic sampler at the same location collects a composite water sample each week for gross alpha and gross beta analysis Weekly samples also are collected by Broomfield from Walnut Creek below Great Western Reservoir and analyzed for gross alpha and gross beta Water entering the Broomfield water treatment plant from the reservoir is monitored monthly for eight VOCs Treated Broomfield tap water is also monitored weekly for gross alpha and gross beta, and monthly for eight VOCs (CDH, 1989) CDH conducts quarterly sampling of Great Western Reservoir for selected herbicides, pesticides, metals, base neutral acids (BNAs), and radionuclides Broomfield water treatment plant influent from Great Western Reservoir is analyzed weekly by CDH for selected radionuclides (CDH, 1990a)

The RFP, Broomfield, and CDH surface and tap water monitoring programs have produced a large volume of data to assess the potential impacts from RFP releases on Site 200 surface water quality The monitoring is conducted in part to ensure that the RFP is in compliance with applicable state and federal water quality standards Applicable standards have varied since the opening of the RFP in 1951 Currently applicable standards for the RFP include

- The National Pollution Discharge Elimination System (NPDES) standards for the RFP, first issued in 1974, which limit nonradioactive discharges from the plant
- State drinking water standards for radioactive contaminants in community water systems, promulgated in 1977
- Colorado Water Quality Control Commission (CWQCC) temporary water quality standards for both radioactive and nonradioactive contaminants, which were adopted in July 1989 for all tributaries to Great Western Reservoir from the RFP

Descriptions of these standards, and information about RFP compliance with the standards, are contained in the RFP monthly and annual environmental monitoring reports (Dow et al , 1971-1989)

2 2 STANDLEY LAKE (Site 201)

Site 201 encompasses Standley Lake, off-site reaches of Woman Creek (which flows into the reservoir from the RFP), and downstream surface water features possibly impacted by outflow from the reservoir (Figure 2-1) Portions of Woman Creek within the boundaries of the RFP will be investigated as RFP OU 5 and are not included in Site 201

2 2 1 Location and Description

Standley Lake is a large reservoir located approximately 2 mi (3 2 km) southeast of the RFP's eastern boundary (Figure 2-1) in Sections 16, 17, 20, 21, 22, and 28, T2S R69W Uses of the reservoir include municipal water supply and recreation The reservoir has been owned by The Farmers Reservoir and Irrigation Company of Brighton, Colorado since its construction between 1909-1919 Although the dam has undergone periodic maintenance and reconstruction, most recently in 1978, Standley Lake's present volume of 43,000 acre-feet (5,300 hectare-meters) has remained relatively unchanged since its construction Approximately 67 percent of the reservoir water is used as municipal water supply for the cities of Westminster, Northglenn and Thornton The remaining 33 percent is transported through irrigation ditches to agricultural areas northeast of the lake, primarily between Broomfield and Fort Lupton Standley Lake receives approximately 96 percent of its water from Clear Creek via an irrigation ditch, but is also fed by Woman Creek (Figures 2-1 and 2-3), which drains the southern side of the RFP (Farmers, 1990)

A geologic characterization of Standley Lake was performed by Mineral Systems, Inc in 1982 to provide data for the enlargement of the dam and reservoir Bedrock outcrops at various locations around the lake consist of claystone with interbedded sandstone lenses, probably of the Arapahoe Formation These units dip gently to the northeast Overlying the bedrock are surficial deposits averaging 15-20 ft (5-7 m) thick, consisting of a series of alluvial terraces, colluvium, and minor other deposits No faults have been identified in the area (Hydro-Triad, 1982) Although other site-specific information concerning Standley Lake geology and ground water hydrology are lacking, it is expected that conditions in the immediate vicinity of the reservoir are similar to those described in Section 2 1 2 1 for Great Western Reservoir

Within the RFP boundary, the Woman Creek drainage contains the two C-series holding ponds, Ponds C-1 and C-2 (south and east of the main production area, respectively) (Figures 2-1 and 2-2) Pond C-1 receives flow from Woman Creek This flow is diverted around Pond C-2 and back into the Woman Creek channel downstream of Pond C-2 Pond C-2 receives surface runoff from the South Interceptor Ditch which collects surface runoff from the southern half of the RFP main production area (Rockwell, 1988a) The South Interceptor Ditch runs along the south (downgradient) side of the main production area, between the controlled area and Woman Creek (Figure 2-2) Pond C-2 water formerly was discharged into Woman Creek in accordance with the NPDES permit for the RFP More recently, water was pumped from Pond C-2 into a treatment facility, then through an aboveground pipeline to the Broomfield Diversion Ditch, where it was discharged in accordance with an amended NPDES permit and an agreement with the City of Broomfield This discharge agreement expired at the end of 1990, and no water has been discharged from Pond C-2 since this time The DOE has recently examined the possibility of discharging Pond C-2 water to Mower Reservoir (see Section 2 3 1) These surface water controls within the RFP allow the RFP to effectively prevent runoff from the RFP main production facility (the controlled area shown in Figure 2-1) from reaching Standley Lake

2 2 2 Environmental Investigations

Radioactive materials released from the RFP may have been transported to Standley Lake through surface water (primarily in suspended sediments) and/or airborne particulates (fugitive dust) Between 1952 and 1973, the RFP discharged water treatment facility filter backwash into Pond C-1, which discharges into Woman Creek (Rockwell, 1988b) At present, only buffer zone surface runoff and natural ground water seepage flow into the Woman Creek drainage within the RFP boundary (Dow et al , 1971-1989)

The following sections present chronological summaries of environmental studies conducted to date of Site 201 Analytical results from these studies are summarized in Table 2 2 Many of the studies conducted at Great Western Reservoir (Section 2 1 3) also included Standley Lake Reports associated with these studies are incorporated by reference to the documents in Appendix D and to the bibliography in Section 6 0

TABLE 2.2

STANDLEY LAKE PLUTONIUM ANALYTICAL DATA

Data Source	Range (pCi/g or l)	Average (pCi/g or l)	Number of Data Points
"Radioactivity Levels in the Environs of the Rocky Flats Plutonium Plant, Golden, Colorado, 1970," April 1971, by EPA (Appendix D, Document D-1)	Surf Sed[1] 0 04-0 05	0 045	2
	Water* <0 02	<0 02	1
"Radioactivity Levels in the Environs of the Rocky Flats Plutonium Plant, Colorado, 1970, Part II," December 1973, by EPA (Appendix D, Document D-2)	Surf Sed. 0 05-0 21	0 13	2
	Sed Core 0 09-0 37	0 19	2
	Water* <0 02	<0 02	1
"Plutonium Levels in the Sediment of Area Impoundments Environs of the Rocky Flats Plutonium Plant - Colorado," February 1975, by EPA (Appendix D, Document D-3)	Surf Sed. <0 02-0 17	0 07	17
	Sed Core <0 03-0 16	0 07	8
"Survey of Reservoir Sediments," August 1974, by Dow Chemical (Appendix D, Document D-4)[2]	Surf Sed. 0 13-3 16	1 3	6
	Sed Core 0 00007-0 109	0 016	8
"Radionuclide Concentrations in Reservoirs, Streams and Domestic Waters Near the Rocky Flats Installation," April 1981, by Battelle PNL (Appendix D, Document D-5)[3]	Surf Sed. 0 15-0 29	0 22	3
	Water* 0 0015	0 0015	1
"Time Pattern of Off-site Plutonium Contamination from Rocky Flats Plant by Lake Sediment Analyses," July 1978, by DOE (Appendix D, Document D-6)	Sed Core 0 03-0 56	0 15	2
"Standley Lake Sediment Sample Collection Summary," September 1984, by Rockwell International (Appendix D, Document D-10)	Surf Sed. ND[4]-0 55	0 04	63
	Sed Core 0 052-0 61	0 12	2

1 Surface sediment grab sample--typically represents upper 5 cm of sediments

2 Results are for samples collected in 1973 by EPA and split with DOE Surface sediment grabs analyzed by Rocky Flats laboratory, sediment cores analyzed by Battelle Pacific Northwest Laboratory and Lawrence Livermore National Laboratory Reported values from Rocky Flats laboratory are much higher than those recorded in other Standley Lake sampling programs Very low confidence in these values

3 Collected numerous water and sediment samples in which plutonium concentrations were not measured

4 ND = below Rocky Flats laboratory detection limit of 0 002 pCi/g

2 2 2 1 Reservoir and Drainage Sediments

The EPA collected four surface grab samples and two cores of bottom sediments from Standley Lake in 1970 The results indicated possible plutonium contamination above the estimated ≤0 1 pCi/g (0 0037 Bq/g) baseline concentration (worldwide atmosphere fallout) in the deeper areas of the reservoir EPA concluded that elevated plutonium in Standley Lake resulted from unspecified releases from the RFP, and speculated that these releases occurred from surface water erosion and transport of plutonium-contaminated soil (Appendix D, Documents D-1 and D-2)

EPA resumed their investigation of plutonium in surface water sediments east of the RFP in 1973 Analysis of seventeen surface grab samples and eight cores of Standley Lake sediments yielded plutonium concentrations above estimated baseline concentrations in only two of the surface grab samples Plutonium concentrations in the cores taken at the locations of these grab samples were similar to baseline concentrations (≤ 0 1 pCi/g) EPA believed the cores to be more representative of actual conditions at the two locations, and concluded that the collective sampling effort did not indicate any discernable plutonium contamination in Standley Lake sediments attributable to RFP releases (Appendix D, Document D-3)

During a 1974 investigation of radionuclides in the sediments of reservoirs and streams near the RFP, Battelle Pacific Northwest Laboratories collected eight surface sediment grab samples and a single sediment core from Standley Lake Several samples contained plutonium above EPA estimated baseline levels of ≤0 1 pCi/g (0 0037 Bq/g) Based upon the single core sample, Battelle extrapolated total plutonium and americium inventories for Standley Lake sediments at 60 and 18 mCi (2 2 and 0 7 GBq/g), respectively The core also suggested that cesium-137 levels in Standley Lake sediments were typical of atmospheric fallout baseline levels The Battelle study did not attempt to define the historical source of Standley Lake plutonium contamination (Appendix D, Document D-5)

Separate studies of plutonium in the surface water systems in the vicinity of the RFP concluded that (1) plutonium rapidly and almost irreversibly attaches itself to clay sediments (CSU, 1974), and, (2) plutonium in surface water impoundments does not move very far or very rapidly

through subsurface waters, meaning that the majority of the plutonium released through RFP surface waters was contained in the on-site holding ponds (Dow, 1975)

The DOE collected two sediment cores from Standley Lake in August 1976, and determined through correlation of peak radionuclide concentrations in the longer core that it represented approximately fourteen years of sedimentation (1962-1976) This dating enabled DOE to calculate an average sedimentation rate for the core location of 1 3 in/yr (3 4 cm/yr), and to conclude that plutonium concentrations in the core location exceeded baseline levels since 1966, peaked in 1969, and declined after 1969 The report attributed 70 percent of the plutonium in Standley Lake to releases from the RFP and speculated that this plutonium was transported both by airborne particulates and by soil erosion within the lake drainage basin (i e surface water) The time correlation of plutonium deposition in the core corresponded with the known period of windborne plutonium release from the 903 Pad at the RFP (Figure 2-1) (Appendix D, Document D-6)

Rockwell International conducted an extensive sediment sampling program at Standley Lake in 1984 to evaluate sediment plutonium concentrations and to compare the results with previous work A total of 63 surface sediment grab samples and four sediment cores were collected by Rockwell, of which seven grab samples and two cores were collected jointly with the City of Westminster The results of this study were not published in report form, but were summarized in public meetings A maximum concentration of 0 61 pCi/g (0 02 Bq/g) was detected at a depth of 6 3-7 1 in (16-18 cm) in one core The maximum plutonium concentration measured in the surface sediment grab samples, which potentially represented a sediment depth of several inches, was 0 55 pCi/g (0 018 Bq/g) (Appendix D, Document D-10)

In 1989, the CDH analyzed various species of fish collected from Standley Lake to determine if they were safe for human consumption The fish were analyzed for selected metals, radionuclides (including plutonium-239, plutonium-240, and cesium-137), and priority organic pollutants No radionuclides were detected in the fish, however, low concentrations of cadmium, mercury, selenium, and the pesticides DDT, DDE, DDD, and malathion were detected in some or all species The report stated that the source(s) of these contaminants was indeterminate, but

that none of the contaminants detected were unique to the RFP It was concluded that the contaminants may have originated from a variety of sources in the watershed, including water diverted from Clear Creek, which contributes 96 percent of the influent to Standley Lake (Appendix D, Document D-11)

2 2 2 2 Reservoir and Drainage Water Quality

The quality of surface water in Woman Creek and Standley Lake has been monitored since shortly after the RFP opened in 1951 Tap water is also monitored for prospective RFP-derived contaminants in a number of municipalities around the RFP, including the cities of Westminster, Thornton, and Northglenn, which are supplied by Standley Lake In addition, several historical studies have focused on potential impacts to Standley Lake water quality as a result of RFP releases

Historical Studies

A 1973 study by the EPA concluded that dissolved plutonium concentrations in water samples from Standley Lake were less than atmospheric fallout-derived baseline concentrations of <0 03 pCi/l (0 001 Bq/l) Dissolved uranium concentrations were less than the expected natural background of 2 5 micrograms per liter (Appendix D, Document D-3)

Battelle Pacific Northwest Laboratories analyzed Standley Lake water as part of their investigation of radionuclide concentrations in reservoirs, streams and domestic waters near the RFP Plutonium-239, plutonium-240, and americium-241 concentrations in Standley Lake water were above the expected atmospheric fallout background, which was not specifically quantified in this study, but were orders of magnitude lower than the EPA National Primary Drinking Water Regulation of 15 pCi/l (0 55 Bq/l) for total long-lived alpha activity (exclusive of radon and uranium) Concentrations of these three radionuclides were below detection limits of 4.5×10^{-4} pCi/l (1.7×10^{-5} Bq/l) in Westminster tap water (Appendix D, Document D-5)

Filtration of Standley Lake influent occurs at the Northglenn, Thornton, and Westminster water treatment plants Discussions with personnel at each of these facilities indicate that filter backwash sludge is not and has not previously been analyzed for plutonium or gross alpha activity

Routine Monitoring

Routine monitoring of surface water within and around the RFP, of all effluent streams leaving the RFP, and of tap water in municipalities around the RFP has been conducted since shortly after the RFP opened in 1951 Specific sampling and analytical protocols have varied throughout the history of the surface water monitoring program Information regarding sample locations, analytical protocols, analytical results, and compliance with applicable state and federal water quality standards has been summarized since 1971 in the RFP monthly and annual environmental monitoring reports (Dow et al , 1971-1989) The surface water monitoring program is also summarized in the RFP environmental impact statement (DOE, 1980)

The cities of Northglenn, Thornton, and Westminster each monitor raw water influent from Standley Lake at their respective water treatment plants for VOCs, gross alpha and gross beta Westminster also monitors treated (tap) water for gross alpha and gross beta Woman Creek is sampled immediately east of the RFP boundary once each month by the City of Thornton and analyzed for 59 VOCs Another location along Woman Creek is sampled weekly for gross alpha and gross beta analysis Standley Lake water is sampled monthly near the Westminster treatment plant inlet and analyzed for 59 VOCs Water is also sampled monthly near the Standley Lake dam at six different depths and analyzed for gross alpha and gross beta (CDH, 1989) CDH conducts quarterly sampling of Standley Lake for analyses of selected herbicides, pesticides, metals, BNAs, and radionuclides Westminster water treatment plant influent from Standley Lake is analyzed weekly by CDH for selected radionuclides (CDH, 1990a)

The surface and tap water monitoring programs conducted by RFP, CDH, and the cities supplied by Standley Lake have produced a large volume of data to assess the potential impacts from RFP releases on Site 201 surface water quality The monitoring is conducted in part to ensure that the RFP is in compliance with applicable state and federal water quality standards Applicable

standards have varied since the opening of the RFP in 1951 Currently applicable standards for the RFP include

- NPDES standards for the RFP, first issued in 1974, which limit nonradioactive discharges from the plant
- State drinking water standards for radioactive contaminants in community water systems, promulgated in 1977
- CWQCC temporary water quality standards for both radioactive and nonradioactive contaminants, which were adopted in July 1989 for all tributaries to Great Western Reservoir from the RFP

Descriptions of these standards, and information about RFP compliance with the standards, are contained in the RFP monthly and annual environmental monitoring reports (Dow et al , 1971-1989)

2 3 MOWER RESERVOIR (Site 202)

Site 202 encompasses Mower Reservoir, off-site reaches of the irrigation ditch which feeds the reservoir from Woman Creek, and downstream surface water features possibly impacted by outflow from the reservoir (Figure 2-1) Portions of this irrigation ditch within the boundaries of the RFP are part of RFP OU 6 and are not included in Site 202

2 3 1 Location and Description

Very little documentation exists for Mower Reservoir, a small, privately-owned impoundment located just southeast of the RFP in Section 18, T2S R69W The reservoir is fed by Woman Creek via Mower Ditch, an irrigation ditch that originates within the RFP boundary (Figure 2-3) Mower Reservoir is used for agricultural purposes, primarily cattle watering and irrigation, and fluctuates in capacity depending upon water supply and demand It covers an area of approximately 9 acres (3 6 hectares) and is roughly 50 ft (15 m) deep at its deepest point (Personal communication, 1990) Outflow from Mower Reservoir flows southeast from the reservoir, eventually discharging to Standley Lake (Figure 2-3) Mower Reservoir is located on land which was the subject of a lawsuit against the RFP by several landowners, alleging contamination of the land surface by releases from the plant (DOE, 1991a)

No site-specific information is available for geologic and groundwater conditions at Mower Reservoir The ground water hydrogeological setting at Mower Reservoir is expected to be similar to that described for Great Western Reservoir (Section 2 1 3 1), while surface water pathways from the RFP to Mower Reservoir are similar to those described for Standley Lake (Section 2 2 1)

The DOE recently examined the possibility of discharging water from RFP holding Pond C-2 to Mower Reservoir via Woman Creek and Mower Ditch (Figure 2-3) The following conditions would have to be met in order to discharge Pond C-2 water to Mower Reservoir

- All site-specific CWQCC discharge standards would have to be met by the RFP (see Section 2 2 2 2)
- Permission would have to be obtained from the owner of Mower Reservoir
- Assurance would have to be obtained from the reservoir owner that the water would be used only for agricultural purposes

2 3 2 Environmental Investigations

In contrast to the extensive historical sampling data available for Great Western Reservoir and Standley Lake, only very limited data have been collected to characterize Mower Reservoir Because the reservoir is not a public water supply, its water quality is not monitored and has not previously been evaluated RFP-derived contaminants in Mower Reservoir are believed to have been transported primarily as airborne particulates, and to a lesser degree by surface water through the Woman Creek drainage, which may have contributed to plutonium concentrations in Standley Lake sediments (see Section 2 2 2) It can be inferred that contaminant concentrations resulting from releases into Woman Creek would be similar for Mower Reservoir and Standley Lake, while concentrations resulting from airborne releases, and from erosion and transport of contaminated soils by surface runoff, would be similar for Mower Reservoir and Great Western Reservoir

Mower Reservoir sediments were sampled in 1970 during EPA's initial study of radioactive contamination in the aquatic environs of the RFP A total of four surface sediment grab samples were collected Plutonium concentrations in these samples ranged from 0 09-0 18 pCi/g and

averaged 0 14 pCi/g, slightly exceeding EPA's estimated baseline concentration of $\leq$ 0 1 pCi/g (Appendix D, Documents D-1 and D-2) No further characterization of Mower Reservoir contamination has been conducted since this 1970 sampling effort

Numerous investigations have focused on elevated plutonium concentrations in surface soils around Mower Reservoir (DOE, 1991a) These studies have concluded that the primary source of the plutonium was windborne particulates from the 903 Pad (Figure 2-1) It is expected that Mower Reservoir received similar amounts of plutonium through airborne transport as the nearby land surface

2 4 OTHER RELEVANT STUDIES

Several proposed or ongoing investigations within the boundaries of the RFP may produce data which is relevant to the OU 3 reservoirs Although investigations at on-site OUs have progressed to varying stages of completion, most are in the initial assessment stage Investigations of Woman Creek (OU 5) and Walnut Creek (OU 6) will help to determine the extent to which these drainages were pathways for off-site contamination which might eventually have reached Standley Lake and Great Western Reservoir Studies of surface soil contamination in the eastern part of the RFP as part of the ongoing investigation of the 903 Pad and associated on-site contamination (RFP OU 2) may elucidate the role of wind in transporting contaminants to the OU 3 reservoirs, particularly Mower Reservoir

In 1988, the Colorado School of Mines (CSM) presented a proposal to the RFP to study radionuclides in the sediments of Colorado Front Range lakes which had not been affected by releases from the plant (CSM, 1988) As a result of this proposal, a study was conducted for the RFP by CSM of Halligen Reservoir and Wellington Lake, located north of Fort Collins, Colorado and southeast of Bailey, Colorado, respectively The objectives were to more firmly establish baseline radionuclide concentrations due to atmospheric fallout so that "excessive" values could be operationally defined, to compare sedimentation rates for the "background" reservoirs with those for reservoirs near the RFP, and to determine whether radionuclides were subject to any post-depositional bioturbation The study determined that plutonium concentrations in the sediments of the two reservoirs peaked at 0 19 $\pm$0 02 pCi/g (0 007 $\pm$0 00074 Bq/g), and proposed

this value as a baseline concentration for plutonium in Colorado Front Range reservoirs (CSM, 1990) This level is somewhat higher than EPA's estimated plutonium baseline concentration of ≤0 1 pCi/g (0 0037 Bq/g) The CSM study was presented to the RFP in May 1990, and has not yet been formally reviewed by the RFP or published for the scientific community outside the RFP

2 5 SITE DEMOGRAPHICS

The population, economics, and land use of the areas surrounding the RFP are described in a 1989 Rocky Flats vicinity demographics report by DOE (DOE, in press) This report divides general use of areas within zero to 10 mi (zero to 16 km) of the RFP into residential, commercial, industrial, parks and open spaces, agricultural and vacant, and institutional classifications, and considers current and future land use near the plant

2 5 1 Current Use

The majority of residential use within five mi (eight km) of the RFP is located immediately north and southwest of Standley Lake Single (unincorporated) residents are located in the vicinity of Great Western Reservoir and Mower Reservoir Figure 2-4 shows the 1989 population distribution within areas up to five miles from the RFP Commercial development is concentrated near the residential developments north and southwest of Standley Lake, and around the Jefferson County Airport approximately 1 5 mi (2 4 km) northeast of Great Western Reservoir Industrial land use within five mi (eight km) of the plant is limited to quarrying and mining operations Open Space lands are located northeast of Great Western Reservoir, near the city of Broomfield, and in small parcels adjoining major drainages and small neighborhood parks in the cities of Westminster and Arvada Standley Lake is surrounded by Standley Lake Park Irrigated and nonirrigated cropland, producing primarily wheat and barley, are located northeast of the RFP near the cities of Broomfield, Lafayette, and Louisville, north of the RFP near Louisville and Boulder, and in scattered parcels adjacent to Mower Reservoir and Great Western Reservoir Several horse operations and small hay fields are located west of Standley Lake The demographics report characterizes much of the vacant land adjacent to the RFP and the reservoirs as rangeland (DOE, in press)

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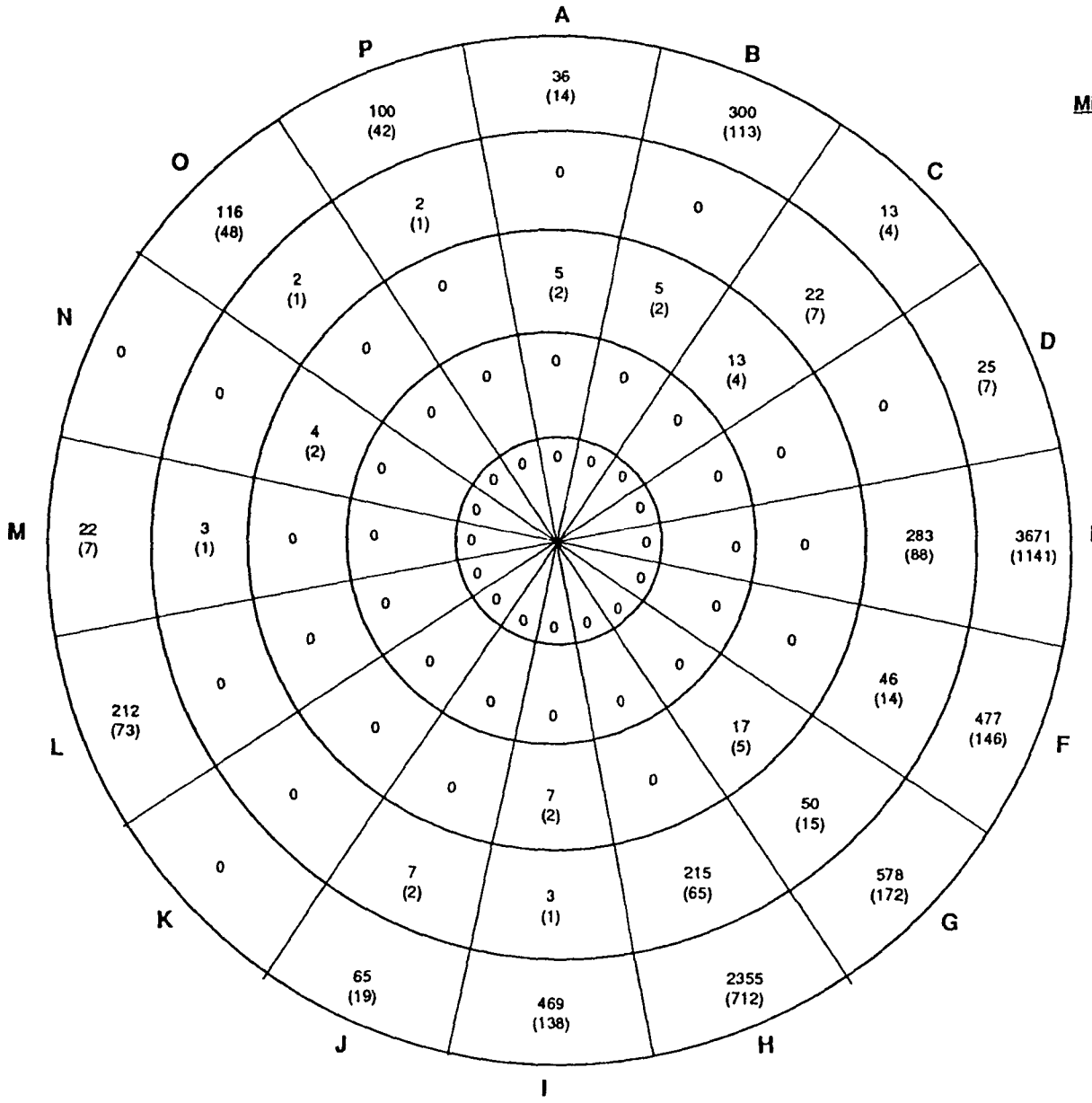
KRONER 3-21-91	CJR 3-22-91	TDK 3-22-91	304923-A27



Miles	Sector Name
0 1	Sector 1
1 2	Sector 2
2 3	Sector 3
3 4	Sector 4
4 5	Sector 5

SOURCE DOE 1989 POPULATION ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT (IN PRESS)

FIGURE 2-4
1989 POPULATIONS AND (HOUSEHOLDS), SECTORS 1-5

Included within Site 199 of RFP OU3 are two contiguous parcels of land totaling 350 acres (142 hectares) which were determined to contain plutonium in soil in excess of a CDH special construction requirements standard of 0 9 pCi/g (0 03 Bq/g) (DOE, 1991a) The parcels of land are directly south of Great Western Reservoir and west/northwest of Mower Reservoir, and are owned by the City of Broomfield and Jefferson County, respectively These lands were part of a larger area adjacent to the RFP which was the subject of a lawsuit by landowners against the United States between 1975-1985 The lawsuit settlement agreement required that the RFP remediate the Broomfield and Jefferson County acreage To date, soil plutonium concentrations have been reduced to below the remedial action target level of 0 9 pCi/g on 120 acres (48 hectares) of the Jefferson County acreage adjacent to Mower Reservoir Concentrations on the remaining 120 acres of Jefferson County land, and on the 100 acres of Broomfield land south of Great Western Reservoir, may still exceed 0 9 pCi/g The Jefferson County land was dedicated to the county Open Space program Rather than allow immediate use of the land as Open Space, the county has chosen to prevent public access to this land until remedial activities are completed The Broomfield land serves as part of a buffer zone around Great Western Reservoir, and is also excluded from public access (DOE, 1991a)

2 5 2 Future Use

Future land use in the vicinity of Sites 200-202 most likely involves continued suburban expansion, increasing the density of residential, commercial, and perhaps industrial land use in the areas The expected trend in population growth in the vicinity of the RFP is addressed in the DOE demographics study (DOE, in press) This report considers expected variations in population density by comparing the current (1989) setting to population projections for the years 2000 and 2010 A 21-year profile of projected population growth in the vicinity of the RFP can thus be examined The DOE projections are based primarily upon long-term population projections developed by the Denver Regional Council of Governments (DRCOG)

Expected population density and distribution around the RFP for the years 2000 and 2010 are shown in Figures 2-5 and 2-6, respectively Table 2 3 summarizes the population data presented in Figures 2-4, 2-5, and 2-6 Sectors 3, 4, and 5 depicted in these figures are relevant to the risk

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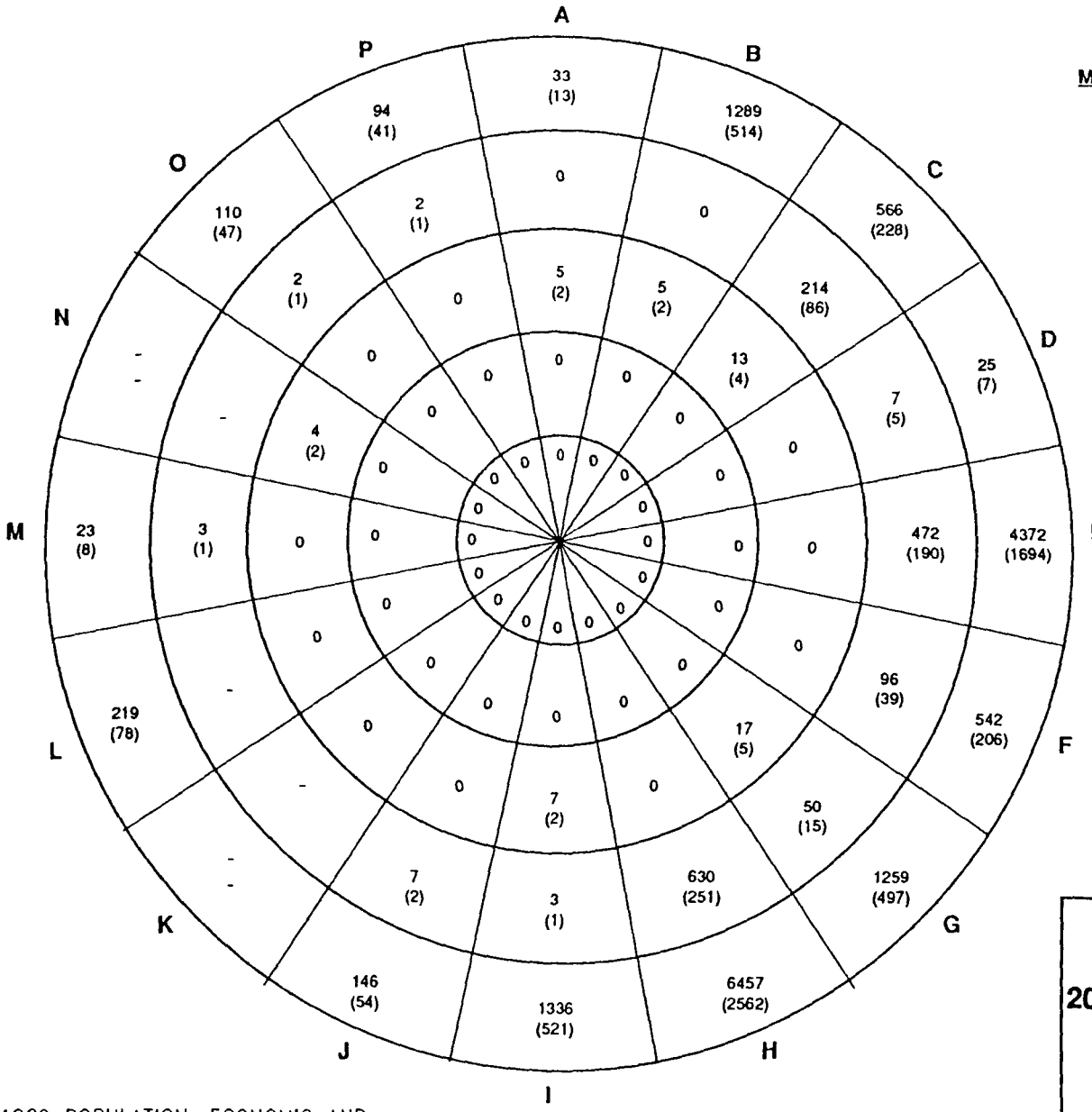
3-21-91	APPROVED BY	3-22-91	
	TDK		



Miles	Sector Name
0 1	Sector 1
1 2	Sector 2
2 3	Sector 3
3 4	Sector 4
4 5	Sector 5

SOURCE DOE 1989 POPULATION ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT (IN PRESS)

FIGURE 2-5
2000 POPULATIONS AND (HOUSEHOLDS), SECTORS 1-5

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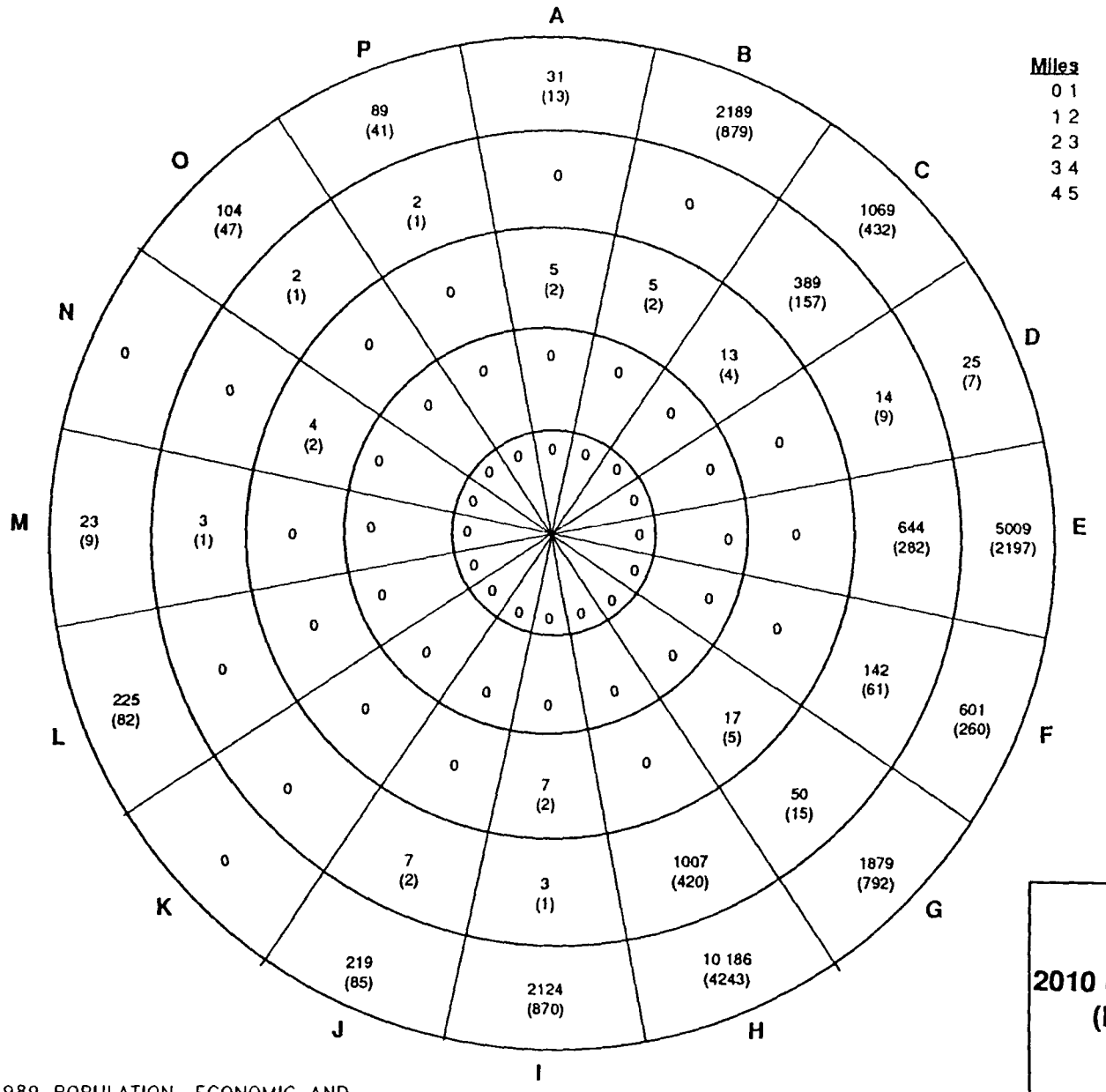

Miles	Sector Name
0 1	Sector 1
1 2	Sector 2
2 3	Sector 3
3 4	Sector 4
4 5	Sector 5

SOURCE DOE 1989 POPULATION ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT (IN PRESS)

FIGURE 2-6
2010 POPULATIONS AND (HOUSEHOLDS), SECTORS 1-5

TABLE 2.3

CURRENT AND PROJECTED POPULATION IN THE VICINITY OF THE ROCKY FLATS PLANT

Sector	Segment							Sum
	B	C	D	E	F	G	H	
Year: 1989								
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	5	13	0	0	0	17	0	35
4	0	22	0	283	46	50	215	616
5	300	13	25	3,671	477	578	2,355	7,419
SUM	305	48	25	3,954	523	645	2,570	8,070
Year: 2000								
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	5	13	0	0	0	17	0	35
4	0	214	7	472	96	50	630	1,469
5	1,289	566	25	4,372	542	1,259	6,457	14,510
SUM	1,294	793	32	4,844	638	1,326	7,087	16,014
Year: 2010								
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	5	13	0	0	0	17	0	35
4	0	389	14	644	142	50	1,007	2,246
5	2,189	1,069	25	5,009	601	1,879	10,186	20,958
SUM	2,194	1,471	39	5,653	743	1,946	11,193	23,239

Source DOE (in press)

assessment presented in Section 4 0, while sectors 1 and 2 represent property within the RFP boundary In addition, only radial Sectors B through H are considered relevant to Sites 200-202

It is concluded in Section 4 0 that windborne particulates from exposed sediments is the most significant potential exposure pathway from the reservoirs which can affect human receptors

The projected population growth in the next 20 years in areas typically downwind of the reservoirs (primarily Standley Lake) may increase the number of potential receptors from the airborne pathway with the exception of one study in which the RFP measured higher concentrations in samples split with EPA (Appendix D, Document D-4) It is repeated here that, with the exception of a study in which the RFP laboratory measured much higher plutonium concentrations in sample splits than did EPA (Appendix D, Document D-4), the peak plutonium concentration measured in Standley Lake sediments in past studies is 0 61 pCi/g (Table 2 2) This peak was found in the deeper water area of the reservoir (i e , not prone to exposure and entrainment by wind), and the sediments containing the higher concentrations have been buried by subsequent sedimentation Even if these sediments were somehow exposed to airborne entrainment, the peak concentrations are believed to be less than the CDH special construction requirements standard for plutonium in soil of 0 9 pCi/g, which was promulgated to protect potential receptors against airborne exposure This topic is addressed in more detail in Section 4 0 Extensive routine water quality monitoring of Standley Lake, Great Western Reservoir, and municipal tap waters derived from these reservoirs indicates that plutonium in the reservoir sediments has had no measurable impact on water quality, meaning that probable increases in the populations supplied by the reservoirs will not constitute an increase in potential receptors via the ingestion pathway

It is assumed in Section 4 0 that the present use of Sites 200-202 will remain unchanged in the foreseeable future

3.0 CONCEPTUAL MODEL OF CONTAMINANT FATE AND MOBILITY

Utilizing the information obtained in past studies (Section 2.0), a conceptual model of contaminant transport and exposure pathways for Sites 200-202 is presented here for use in the evaluation of the potential risks of reservoir contamination to human health.

The primary purpose of the conceptual model is to aid in identifying exposure pathways by which populations may be exposed to contaminants from a site The EPA defines an exposure pathway as " a unique mechanism by which a population may be exposed to the chemicals at or originating from the site " (EPA, 1989) As shown in Figure 3-1, an exposure pathway must include a contaminant source, a release mechanism, a transport medium, an exposure route, and a receptor An exposure pathway is not complete without each of these five components

The general conceptual model for Sites 200-202 is shown in Figure 3-2 Figure 3-2 identifies potential components of completed exposure pathways for the reservoirs and potential interactions between each component The individual components of the exposure pathway are defined as follows.

- Contaminant Source: For purposes of this conceptual model, the contaminant source is the sediment and water of the reservoirs and their influent and effluent drainages (limited to off-site reaches of drainages flowing from the RFP) A distinction is made between dry and saturated sediments in the model because potential exposure pathways differ significantly for dry and saturated sediments Because some contaminants at Sites 200-202 have been traced to past releases from the RFP, the plant is shown in the model as a historical contaminant source to the reservoirs and drainages

- Release Mechanism: Release mechanisms are physical and/or chemical processes by which contaminants are released from the source. The conceptual model identifies mechanisms which release contaminants directly from the source and those which release contaminants from transport media (i e , secondary release mechanisms) Numerous potential release mechanisms and secondary release mechanisms exist for Sites 200-202, as shown in Figure 3-2

- Transport Medium Transport media are the media into which contaminants are released from the source and from which the contaminants are in turn released to a receptor (or to another medium by a secondary release mechanism) Potential transport media for Sites 200-202 include air, surface water, ground water, and biota (both flora and fauna)

DRAWN BY	RITA HYNA	CHECKED BY	CJR	6-12-91	DRAWING NUMBER 304923-A38
	6/4/91	APPROVED BY	CJR	6-12-91	

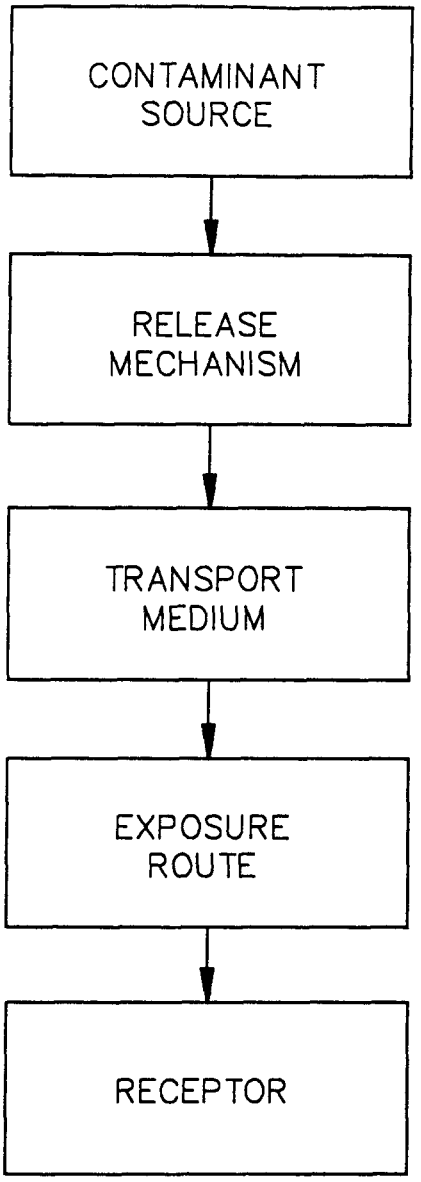

FIGURE 3-1

COMPONENTS OF A COMPLETED EXPOSURE PATHWAY

- Exposure Route Exposure routes are avenues through which contaminants are physiologically incorporated by a receptor. Exposure routes for receptors at Sites 200-202 are inhalation, ingestion, and dermal contact.

- Receptor: For purposes of this conceptual model, receptors are limited to human populations Human receptors for Sites 200-202 include nearby residents and visitors to the sites.

The conceptual model provides a contaminant source characterization and an overview of all the potential exposure pathways that may result from releases from and/or into each transport medium. Some of these pathways have a higher potential for occurrence than others Significant exposure pathways which are common to each reservoir are identified in this section by evaluating the fate and mobility of the contaminant in each potential source and transport medium that is included in the conceptual model. Reservoir-specific exposure pathway issues are then discussed in Section 4 0 Exposure routes and receptors, which are also components of a completed exposure pathway, are addressed in Section 4 0

The various elements of the conceptual model are explained in the following sections.

3 1 CONTAMINANT SOURCE

Contaminant fate and mobility in the waters and sediments that constitute the primary contaminant source media at Sites 200-202 depend on the physical and chemical properties of the source media and the contaminant

3 1 1 Contaminant Characteristics

As discussed in Sections 2 1.3, 2 2 2, and 2 3 2, reservoir sediments at Sites 200-202 have been shown to contain plutonium in excess of expected background concentrations (as measured in Colorado Front Range reservoirs remote from the RFP) Concentrations of beryllium and of selected radionuclides other than plutonium (including americium) have also been characterized in these sediments, although to a much lesser extent than plutonium (Appendix D, Documents D-1, D-3, D-4, D-5, D-6, D-7, and D-8) Americium has been measured in past studies above expected background concentrations in Great Western Reservoir and Standley Lake sediments (Appendix D, Document D-5), and can be expected to occur in the sediments as a result of

plutonium decay, however, sufficient americium data to perform even a qualitative human health risk assessment for Sites 200-202 are lacking None of the available data for plutonium or other potential contaminants from past reservoir studies meet the criteria established by EPA for performing a risk assessment (EPA, 1990a, see Appendix A) For these reasons, and because plutonium concentrations in the reservoir sediments have been well defined from a site characterization standpoint (Appendix D, Documents D-1 through D-10), plutonium is the only contaminant considered for purposes of the qualitative risk assessment (Section 4 0), and is the only contaminant addressed in the following detailed contaminant characterization Reservoir and stream waters in Sites 200 and 201 are routinely monitored for a variety of radioactive and nonradioactive contaminants, and have also been analyzed for plutonium and other selected radionuclides in several past sampling programs (Sections 2 1 3 2 and 2 2 3 2) These monitoring data will be reviewed during evaluation of other potential contaminants of concern under scheduled RFI/RI activities at Sites 200-202.

There are 15 known isotopes of plutonium that decay into other elements at different rates (half-lives range from hours to 387,000 years) (Ames and Rai, 1978) At the typical temperature, pH, and Eh ranges of environmental concern, plutonium will exist largely as either plutonium dioxide (PuO_2) or, in aqueous environments, as a solid hydroxide (Brookins, 1984) The pH of natural environments (e g., meteoric waters, ground water, and freshwater sediments) typically ranges from 4-9, while environmental Eh can be expected to range from +800 to -200 (Brownlow, 1979) The solubility product constant of plutonium hydroxide has been reported as $7x10^{-56}$, indicating virtual insolubility in water (Taube, 1964) Plutonium hydroxide typically adsorbs (attaches) tightly to particulate matter by electrostatic attraction. The majority of plutonium occurring in aqueous environments will be adsorbed onto suspended solids in the water, which settle out in impoundments such as Sites 200-202 to form bottom sediments. Although the presence in the environment of complexing agents such as humic acid may cause increased solubilization of plutonium, solubilization will be minimal under the conditions generally found in the natural environment and plutonium will remain associated with the solid phase (EPA, 1990b)

Based upon the conceptualization of plutonium chemistry in the environment presented above, nearly all of the plutonium in Sites 200-202 is expected to be adsorbed to clay in bottom sediments Studies cited in Sections 2 1 3 and 2 2 2 have indicated that the plutonium in Great Western Reservoir and Standley Lake occurs in distinct sediment horizons in each reservoir The highest plutonium concentrations appear to exist in the deepest areas of the reservoirs

Vertical profiles of the plutonium-bearing horizons developed from sediment cores have also shown that the horizons in each reservoir have been buried to varying depths by subsequent sedimentation. The four cores collected during the most recent Great Western Reservoir study, by Rockwell International in 1983 (Appendix D, Document D-9) showed between 3-9 in (7 5-23 cm) of sediment overlying the plutonium-bearing layer The depth of burial in two cores collected in 1984 by Rockwell International from Standley Lake (Appendix D, Document D-10) ranged from 6 3-8 7 in (16-22 cm) These cores were collected from deeper areas of the reservoirs, where greater sedimentation rates occur and the highest plutonium concentrations have been found to exist. Based on calculated sedimentation rates for the reservoirs, which range from 0 1 in/yr (0 25 cm/yr) in shallow, near-shore areas to 1 4 in/yr (3 6 cm/yr) in deeper areas, it can be inferred that the plutonium-bearing horizons in each reservoir potentially have been covered by an additional 0 7 in (1 8 cm) of sediment in shallow areas and an additional 9 8 in (25 cm) of sediment in deeper areas in the approximately seven years since the Rockwell International studies were conducted.

3 1 2 Sediment and Water Characteristics

In stagnant impoundments such as holding ponds and reservoirs, suspended solids gradually settle out of water to form bottom sediments It has been shown that clay-rich sediments, such as those in Sites 200-202, have an extremely high affinity for plutonium, effectively immobilizing it in the sediment (CSU, 1974). While it is possible that elevated concentrations of complexing agents combined with a relatively high percolation rate through the sediments might mobilize the plutonium, no evidence of plutonium migration in the sediments has been detected (DOE, 1980)

Surface water typically is characterized by oxidizing conditions Density stratification of lake waters in summer, however, can result in a reducing environment in deeper water Under

reducing conditions, the distribution coefficient of plutonium, which is the ratio of concentrations in soil (or sediment) to concentrations in water, may be three- to ten-fold lower than under typical reservoir conditions, meaning that plutonium mobility may increase slightly The magnitude of this increase is not significant, however, in terms of overall plutonium mobility (ANL, 1986)

3 2 RELEASE MECHANISMS AND TRANSPORT MEDIA

As shown in Figure 3-2, potential release mechanisms and transport media can combine in a variety of ways to transport contamination from the reservoirs to human and other biotic receptors These release mechanisms and transport media are potential, and their identification is not meant to imply that they will occur or be significant at the reservoirs The contaminant source characterized in the preceding section is a semi-consolidated mass buried in the sediment of each reservoir, and is in fact not expected to be readily available for release into the environment by any of the mechanisms described below Probabilities of occurrence are discussed in Section 4 0

3 2 1 Plutonium Fate and Mobility in Surface Water

There are five oxidation states of plutonium (Pu) in aqueous solutions· Pu(III), Pu(IV), Pu(V), Pu(VI), and Pu(VII). As discussed in Section 3 1 1, the Pu(IV) oxidation state (i.e , plutonium hydroxide) is the most stable under the oxidizing and near-neutral conditions typical of surface water (DOE, 1991b)

Plutonium hydroxide is extremely insoluble in water, but can nonetheless undergo very limited dissolution in the pH range of environmental interest The solid phase of plutonium hydroxide is a colloidal polymer of neutral or positive charge. Pu(V) and Pu(VI) can coexist as ions with the polymer (DOE, 1991b). Such colloids can contain from 10^6-10^{10} atoms of plutonium (Andelman and Rozzell, 1970) Increasing pH tends to reduce the charge density of the polymer, and at pH>9, it is expected that the colloids become negatively charged, decreasing their affinity for particulates and thus increasing their mobility in surface water (Roxburgh, 1987, DOE, 1991b) Plutonium solubility and subsequent mobility may also increase in the presence of dissolved organic matter, carbonate, fluorides, nitrates, chlorides, or other complexing agents in

the water (Allard and Rydberg, 1983) There is no evidence, however, that this process is occurring in the reservoirs The depths at which concentrations of plutonium decrease to background levels in the sediment columns of Standley Lake and Great Western Reservoir have remained constant in the periods between studies conducted to date when subsequent sedimentation is taken into account (see Appendix D)

Resuspension of plutonium from bottom sediments is possible by processes which disturb the sediments (e g , burrowing organisms, high runoff, or wave action in shallow areas) The resuspended sediments will eventually settle back out, and again become part of the bottom sediments

3 2 2 Plutonium Fate and Mobility in Air

As indicated in Figure 3-2, exposed sediments in near-shore areas of the reservoir may be susceptible to resuspension by wind. This resuspension may be amplified by disturbance (e g , vehicular traffic) Once resuspended in air, particles can move long distances depending upon wind velocity and turbulence Smaller diameter particles will be carried farther; therefore, the size of sediment with which plutonium is associated is critical Numerous studies at the RFP have focused on plutonium association with size fractions of soil particles and have determined representative percentages of respirable plutonium-contaminated soil particles in air (McDowell and Whicker, 1978; Whicker et al , 1974), but the correlation of these studies to reservoir sediments is unknown Sediment size characterization will be conducted as part of scheduled RFI/RI activities for Sites 200-202

3 2 3 Plutonium Fate and Mobility in Ground Water

As discussed in Section 3 2 1, no evidence has been observed in Great Western Reservoir or Standley Lake of solubilization and leaching of plutonium downward in the sediment column towards the ground water table This lack of mobility results primarily from the strong tendency of plutonium to adsorb to clay in the sediments

The migration of plutonium ions in ground water is retarded due to continuous distribution of plutonium between soil and water phases The distribution coefficient (K_d), which quantifies the

tendency to be adsorbed onto a solid particle relative to remaining dissolved, for plutonium is 10^3-10^5 (Allard and Rydberg, 1983). The EPA (1990b) gives a distribution coefficient of $2x10^3$ for plutonium. Plutonium would not be expected to migrate readily in ground water with such high K_d values Furthermore, plutonium will tend to remain adsorbed to solid particles at pH values between 3 and 9 (Roxburgh, 1987) However, it has been shown that plutonium (and americium) bound to colloidal particles in ground water may be unaffected by the forces that act to retard their movement through ground water and may migrate distances far beyond those expected from K_d values alone (Penrose et al , 1990) The Penrose study describes dissolved plutonium and americium from a treated aqueous effluent migrating through a shallow alluvial aquifer derived from volcanic tuff The mineralogy of this aquifer is not described, but fine-grained material described as silty clay may, in fact, be zeolites (hydrated aluminosilicate minerals) The plutonium source, mode of transport, depositional mechanism, and aquifer environment are potentially very different than the reservoir environment at Sites 200-202 Indeed, the Penrose study cautions against extrapolating the results to dissimilar environments and conditions without careful site-specific study. The vertical distribution of plutonium in the reservoir sediments and, if appropriate, the ground water environment at the reservoirs will be studied during scheduled RFI/RI activities at Sites 200-202

4.0 PRELIMINARY HUMAN HEALTH RISK ASSESSMENT

Section 300 430(d) of the NCP (Federal Register March 8, 1990, pg 8709) states that as part of the remedial investigation, a Baseline Risk Assessment (BRA) is to be conducted to determine whether the contaminants of concern identified at the site pose a current or potential risk to human health and the environment in the absence of remedial action For purposes of this report, Table 5 of the IAG Scope of Work modifies this objective for OU 3 by limiting the risk assessment to human health concerns based on a no-action alternative A complete quantitative risk assessment will be performed as part of the scheduled OU 3 RFI/RI activities The following discusses the general aspects of a BRA, and the specific differences of this preliminary assessment.

4 1 BASIS AND PURPOSE OF THE BRA AND THE PRELIMINARY HUMAN HEALTH RISK ASSESSMENT

The major objective of a BRA is to identify and define (quantify) potential human health risks and potential environmental impacts associated with exposure to the constituents present in the various environmental site media The assessment is not intended to estimate the true risks to which human or environmental populations will be subject, rather it presents upper bound estimates of these risks to be used in the remedial decision-making process The true risks are likely to be much lower than their upper bound values It is used as input into the Feasibility Study (FS) to focus on the most appropriate remedies (if any), which reduce identified risks (if any) to acceptable levels The BRA essentially establishes the site baseline conditions from which a selection of the most appropriate type and extent of corrective actions (if any are needed) can be made

BRA Objectives

In general, the major objective of the BRA is attained by identifying and characterizing the following

- Toxicity and quantity of hazardous substances present in each media of concern
- Environmental fate and transport mechanisms within specific environmental media, such as physical, chemical, and biological degradation processes

- Hydrogeological, airborne, surface water, and biota evaluation and assessment
- Potential exposure pathways and extent of actual or expected exposure
- Population at risk
- Extent of expected harm and the likelihood of such harm occurring
- Comparison of predicted intake rates with acceptable levels of exposure based on regulatory and toxicological information
- Development of a site-specific model that will provide a calculation of risk, given site-specific parameters

At most facilities, the principle data source document for conducting the BRA is the RFI or the RI report These will be referred to as an RFI/RI report for purposes of O U No. 3 discussions These include general site characterization information, chemical analytical information, and a detailed description of the hydrogeological regime and predictions of groundwater flow and contaminant transport mechanisms The characterization of site-specific parameters such as airborne contaminant concentrations, types and distribution of biota, occurrence of surface water, and soil contaminant concentrations are also performed during an RFI/RI The BRA presents the data collected during these investigations in the context of potential human and environmental exposure and focuses on the most toxic of the site contaminants The human health aspects of the BRA uses the data and the characterization of the site and contaminant distribution patterns for all environmental media by reinterpreting them in the context of potentially complete exposure pathways leading to human receptors, with one added dimension, namely focusing on the toxic constituents The following discussions focus on the human health aspects of a risk assessment.

Once all potential exposure pathways have been evaluated the carcinogenic risk calculations from each are summed to produce a total risk posed to humans from the contaminants located on-site This value is then compared to the EPA target carcinogenic risk range of 10^{-4} to 10^{-6} The EPA does not require the complete elimination of risk or of all known or anticipated adverse effects, rather it requires protection of human health and the environment. Appendices B and C of this report provide additional information concerning the concepts of risk

In 40 Code of Federal Regulations (CFR) Section 300 430(e)(2)(i)(A)(2) the EPA states that "For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper-bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6}, using information on the relationship between dose and response " Furthermore, the EPA has stated in this section that the 10^{-6} risk level shall be used as the point of departure for determining remediation goals for alternatives when ARARs are not available or are not sufficiently protective because of the presence of multiple contaminants at a site or multiple pathways of exposure, however, this 10^{-6} cumulative risk level is to be used only as a starting point, and does not reflect a presumption that the final decision on remedial action should attain such a risk level It is possible that given site-specific parameters, a calculation that results in a cumulative total risk level of 10^{-4} to the public could still be protective of human health, thus eliminating the need for remedial action

Qualitative Risk Assessment Objectives

Unfortunately, none of the above issues can be quantified in this document due to the type of historical data available for Sites 200-202 Appendix A of this document presents a data useability review of existing documents to evaluate their applicability for use in risk assessment, and concludes that the available data are not adequate to perform a defensible quantitative risk assessment. A quantitative risk assessment will, however, be performed based on EPA guidance (EPA, 1989) as part of the remedial investigation report

Since the requirements of the IAG must still be met, and a quantitative human health risk assessment cannot be performed with existing data, a qualitative human health risk assessment for Sites 200-202 is presented in this section The objectives of this qualitative assessment are to identify all potential exposure pathways which will be evaluated in the RFI/RI, to discuss the relative significance of each pathway by using existing information to make qualitative judgements, and to identify additional information which will be needed to perform a quantitative assessment. The qualitative assessment presented in this report uses the existing information to make judgements concerning the potential exposure pathways and to identify the plausible exposure pathways and qualitative risks which are applicable to the no action alternative for the

reservoirs These judgements are not used, however, to eliminate potential exposure pathways from evaluation during the scheduled RFI/RI activities

The qualitative risk evaluation (based on existing information) for the no action alternative is based on the current uses of the reservoirs In order to provide some estimate of whether there is any imminent threat to human health, a hypothetical (generic) risk assessment has also been provided that uses generic exposure pathway assumptions based on future reservoir use conditions This generic risk assessment does have limitations in that only plutonium is assessed This assessment is provided in Appendix C, and includes discussions of the relative difference in risk based on plutonium concentrations in exposed or resuspended sediments of 0 01 pCi/g, 0 1 pCi/g, 1 pCi/g, and 10 pCi/g The reader may compare the calculations for each pathway to assess if there is agreement between the qualitative description of risk from each pathway with the risk calculated for that pathway in Appendix C

All of the data reviewed (see Section 6 0, Appendices A and C for a list of references) indicate that radionuclides in reservoir and stream sediments are the only contaminants of concern at Sites 200-202 which can be attributed to RFP historical releases A more comprehensive assesment of potential chemicals of concern will be performed during RFI/RI activities Some media specific analyses of plutonium and other radionuclides present at the RFP, such as americium-241 and Hydrogen-3, have been performed at Great Western Reservoir and Standley Lake (Appendix D, Document D-5) However, only plutonium will be addressed specifically in this qualitative risk assessment and in the generic risk assessment (Appendix C), since the potential exposure pathways for the radionuclides of concern are similar (although significance may vary), and significantly more data would be needed to quantitatively address the risks of these other radionuclides A more comprehensive assessment of all contaminants of concern and of the potential exposure pathways will be performed during the scheduled RFI/RI activities

4 2 QUALITATIVE ASSESSMENT CONCEPTUAL APPROACH

Since there is no existing RFI/RI document, this qualitative risk assessment uses hazard rankings (Sections 4 5 1 and 4 7 1) instead of plutonium concentration values, transport equations and receptor dose calculations to make judgements concerning relative magnitude of specific media

occurrence, release probabilities, potential routes of uptake and the ultimate impact on a human receptor As discussed, a generic quantitative risk assessment is also included in Appendix C, so that the relative magnitude of the qualitative hazard ranking can be compared with the numerical magnitude of the exposure pathway analysis provided in Appendix C

The EPA Risk Assessment Guidance (RAG) document states that a completed exposure pathway must have the following four elements (EPA, 1989)

- A source and mechanism of chemical release to the environment
- An environmental transport medium for the released chemical (air, ground water, etc)
- A point of potential human or biota contact with the contaminated medium (exposure point)
- A mode of uptake at the exposure point (ingestion, inhalation, or dermal contact)

If any of these elements are absent, there is no resultant human exposure and consequently no risk For the purposes of this assessment, the term completed exposure pathway will be used only when all four of these elements are present

The qualitative risk assessment presented in this report has been developed as follows

Toxicity Assessment (Section 4 3)
The human health risks associated with radiation exposure are briefly described, with emphasis on exposure to plutonium. A more rigorous toxicity assessment will be performed as part of the scheduled RFI/RI activities, once adequate site-specific data have been collected

Source Term (Section 4 4)
The source term describes the amount and distribution of contaminant (plutonium) found in the reservoirs For Sites 200-202, the source term corresponds to plutonium concentrations in the reservoir sediments The concentration of plutonium in the sediments, and the depths at which it is found, affects the magnitude of any release into other media A more comprehensive

characterization of the extent and magnitude of all contaminants of concern will be performed as part of the scheduled RFI/RI activities

Potential Exposure Pathways (Section 4 5)

Potential exposure pathways for Sites 200-202 are identified based on historical information, and site and contaminant characteristics The relative importance of any individual potential exposure pathway is then assessed by estimating the magnitude of potential exposure, the frequency and duration of these exposures, and the media-specific pathways by which humans are potentially exposed The magnitudes of potential exposures are based upon the sediment contamination being a contamination source for other media Media-specific pathways for the current reservoir use condition (described in Section 2 0) are qualitatively assessed in this section for their relative importance to exposure routes leading to human uptake

Exposure Routes (Mode of Uptake) (Section 4 6)

The various routes of plutonium uptake by humans and other organisms important to human exposure are identified and ranked by relative importance to the risk assessment The risks associated with potential points of human contact are qualitatively assessed based on all identified exposure pathways A description of the behavior of plutonium in biological systems is included in this section Exposure routes for the current land use condition are qualitatively assessed in this section for their relative importance to the risk characterization It is recognized that the ranking of the exposure routes is highly dependent upon the contaminants of concern, and that the rankings developed in the quantitative risk assessment (based on more site-specific data) may vary from those presented in this report.

Risk Characterization (Section 4 7)

The elements developed in preceding sections are combined into a site-specific risk characterization, which evaluates the concentration of plutonium in each media, its likelihood for transport to other media, and its likelihood to impact a human receptor based on current land use conditions The potential exposure pathways are systematically examined, and those which do not meet the criteria of a completed exposure pathway based on current reservoir use conditions (using existing information) are eliminated from the risk assessment. Again, the elimination of

pathways from this qualitative risk assessment does not eliminate these pathways from being evaluated during the scheduled RFI/RI activities

4 3 TOXICITY ASSESSMENT

The purpose of a toxicity assessment is to weigh available evidence regarding the potential for particular contaminants to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects A toxicity assessment is rather straightforward for radionuclides, since the type of effects and the likelihood of occurrence of any one of the number of possible adverse effects from radiation exposure depends on the radiation dose The following provides a summary of human and experimental animal data that establishes the hazards of radiation exposure

4 3 1 Hazard Identification

The foundation of any risk assessment is that two conditions must be met for a risk to be present 1) a hazard (presence of a toxic substance at a concentration where exposure can result in a toxicologically significant dose) must be present, and, 2) exposure (of a receptor) to that hazard must occur If either factor is absent, the hazard or the exposure, there is no risk In simple mathematical terms, the risk is equal to the potency (a measure of the hazard) times the effective dose (a measure of the exposure)

Hazards associated with chemicals are described toxicologically in terms of exposure mode and duration Modes of environmental exposure are characterized as inhalation, ingestion, and direct contact (dermal absorption).

In addition to these exposure categories, health effects are divided into two main categories health consequences that may occur at any exposure level greater than zero (carcinogenicity), and health effects which will not be elicited unless the constituent concentration is above some threshold level (non-carcinogens) For these sites it is assumed that the radionuclide concentrations present will pose a potential of only a carcinogenic hazard to the public as stated

by EPA, and may be used as the sole basis for assessing the radiation related to human health risk at Sites 200-202 (EPA, 1989)

Because carcinogenic effects are believed to be initiated at the molecular level, current regulatory policy is based on the concept that there is no finite dose or threshold below which carcinogens do not exert a potential effect In the case of chemicals exhibiting non-carcinogenic effects, it is believed that organisms have protective mechanisms that must be overcome before the toxic endpoint is manifested

In determining health risks associated with chronic exposure to toxic materials, two categories based on the nature of the health consequences exist. For all health effects associated with chronic exposure to non-carcinogenic toxic materials there is some threshold concentration below which the impact will not occur; however, there is no threshold concentration for carcinogenic toxic constituents Materials that are carcinogenic may also induce other health effects which occur at a lower concentration

In order to evaluate the potential risks posed by plutonium, it is important to understand the toxicity hazards of radiation for different exposure routes. Radiation is defined as the transfer of energy from one place to another Heat, sound, and light are radiation but do not carry enough energy to break the atomic bonds of molecules, however, ionizing radiation, when interacting with matter, has sufficient energy to break the atomic bonds of molecules, and produce (emit) an ejected electron and a positively charged ion Ionizing radiation may be in the form of particles or electromagnetic waves

The principal adverse biological effects associated with ionizing radiation exposures from radioactive substances in the environment are carcinogenicity, mutagenicity, and teratogenicity Carcinogenicity is the ability to produce cancer Mutagenicity is the property of being able to induce genetic mutation, which may be in the nucleus of either somatic (body) or germ (reproductive) cells Mutations in germ cells lead to genetic or inherited defects Teratogenicity refers to the ability of an agent to induce or increase the incidence of congenital malformations as a result of permanent structural or functional deviations produced during the growth and

development of an embryo (more commonly referred to as birth defects) Radiation may induce other deleterious effects at acute doses above about 100 rem, but doses of this magnitude are not normally associated with radioactive contamination in the environment.

Ionizing radiation causes injury by breaking molecules into electrically charged fragments (i e , free radicals), thereby producing chemical rearrangements that may lead to permanent cellular damage. The degree of biological damage caused by various types of radiation varies according to how spatially close together the ionizations occur Ionizing radiation from plutonium (e g , alpha particles) produces high density regions of ionization For this reason, they are called high-LET (linear energy transfer) particles Other types of radiation (e g , x-rays, gamma rays, and beta particles) are called low-LET radiations because of the low density pattern of ionization they produce In equal doses, the carcinogenicity and mutagenicity of high-LET radiations may be an order of magnitude or more greater than those of low-LET radiations, depending on the endpoint being evaluated The variability in biological effectiveness is accounted for by the quality factor used to calculate the dose equivalent This variability has been accounted for in the generic risk assessment developed in Appendix C

4.3 2 Carcinogenesis

An extensive body of literature exists on radiation carcinogenesis in man and animals This literature has been reviewed most recently by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiations (NAS-BEIR Committee) (UNSCEAR, 1977, 1982, 1988, NAS, 1972, 1980, 1988) Estimates of the average risk of fatal cancer from low-LET radiation from these studies range from approximately 0 007 to 0 07 fatal cancers per 100 rem

An increase in cancer incidence or mortality with increasing radiation dose has been demonstrated for many types of cancer in both human populations and laboratory animals (UNSCEAR, 1982, 1988, NAS, 1980, 1988) Studies of humans exposed to internal or external sources of ionizing radiation have shown that the incidence of cancer increases with increased radiation exposure This increased incidence, however, is usually associated with appreciably

greater doses and exposure frequencies than those encountered in the environment Therefore, risk estimates from small doses obtained over long periods of time are determined by extrapolating the effects observed at high, acute doses Malignant tumors in various organs most often appear long after the radiation exposure, usually 10 to 35 years later (NAS, 1980, 1988, UNSCEAR, 1982, 1988) Radionuclide metabolism can result in the selective deposition of certain radionuclides in specific organs or tissues, which, in turn, can result in larger radiation doses and higher-than-normal cancer risk in these organs

Ionizing radiation can be considered pancarcinogenic, i e , it acts as a complete carcinogen in that it serves as both initiator and promoter, and it can induce cancers in nearly any tissue or organ Radiation-induced cancers in humans have been reported in the thyroid, female breast, lung, bone marrow (leukemia), stomach, liver, large intestine, brain, salivary glands, bone, esophagus, small intestine, urinary bladder, pancreas, rectum, lymphatic tissues, skin, pharynx, uterus, ovary, mucosa of cranial sinuses, and kidney (UNSCEAR, 1977, 1982, 1988, NAS, 1972, 1980, 1988) These data are taken primarily from studies of human populations exposed to high levels of radiation, including atomic bomb survivors, underground miners, radium dial painters, patients injected with thorotrast or radium, and patients who received high x-ray doses during various treatment programs Extrapolation of these data to the much lower doses that the public would be exposed to at Sites 200-202 is the major source of uncertainty in determining low-level radiation risks (see EPA, 1989a) It is assumed that no lower threshold exists for radiation carcinogenesis

On average, approximately 50 percent of all of the cancers induced by radiation are lethal The fraction of fatal cancers is different for each type of cancer, ranging from about 10 percent in the case of thyroid cancer to 100 percent in the case of liver cancer (NAS, 1980, 1988) Females have approximately two times as many total cancers as fatal cancers following radiation exposure, and males have approximately 1 5 times as many (NAS, 1980)

Cancer slope factors (CSF) for the ingestion and inhalation of radionuclides likely to be found at Sites 200-202 are presented in Table B 1 CSFs are estimated with mathematical extrapolation models, which extrapolate the effects (cancer-induction) seen at high doses to potential effects

at low doses The CSFs for radionuclides are considered "best estimates," while slope factors for chemicals are computed at the 95 percent confidence level This method for determining risk will be used for any significant exposure to a radionuclide

4 3 3 Mutagenesis

Very few quantitative data are available on radiogenic mutations in humans, particularly from low-dose exposures Some mutations are so mild they are not noticeable, while other mutagenic effects that do occur are similar to nonmutagenic effects and are therefore not necessarily recorded as mutations The bulk of data supporting the mutagenic character of ionizing radiation comes from extensive studies of experimental animals (UNSCEAR, 1977, 1982, 1988, NAS, 1972, 1980, 1988) These studies have demonstrated all forms of radiation mutagenesis, including lethal mutations, translocations, inversions, nondisjunction, and point mutations Mutation rates calculated from these studies are extrapolated to humans and form the basis for estimating the genetic impact of ionizing radiation on humans (NAS, 1980, 1988 UNSCEAR, 1982, 1988) The vast majority of the demonstrated mutations in human germ cells contribute to both increased mortality and illness (NAS, 1980, UNSCEAR, 1982) Moreover, the radiation protection community is generally in agreement that the probability of inducing genetic changes increases linearly with dose and that no "threshold" dose is required to initiate heritable damage to germ cells

The incidence of serious genetic disease due to mutations and chromosome aberrations induced by radiation is referred to as genetic detriment Serious genetic disease includes inherited ill health, handicaps, or disabilities Genetic disease may be manifest at birth or may not become evident until some time in adulthood Radiation-induced genetic detriment includes impairment of life, shortened life span, and increased hospitalization The frequency of radiation-induced genetic impairment is relatively small in comparison with the magnitude of detriment associated with spontaneously arising genetic diseases (UNSCEAR, 1982, 1988)

4 3 4 Teratogenesis

Radiation is a well-known teratogenic agent The developing fetus is much more sensitive to radiation than the mother The age of the fetus at the time of exposure is the most important

factor in determining the extent and type of damage from radiation The malformations produced in the embryo depend on which cells, tissues, or organs in the fetus are most actively differentiating at the time of radiation exposure Embryos are relatively resistant to radiation-induced teratogenic effects during the later stages of their development and are most sensitive from just after implantation until the end of organogenesis (about two weeks to eight weeks after conception) (UNSCEAR, 1986, Brent, 1980) The brain appears to be most sensitive during development of the neuroblast (these cells eventually become the nerve cells) The greatest risk of brain damage for the human fetus occurs at 8 to 15 weeks, which is the time the nervous system is undergoing the most rapid differentiation

4 3 5 Summary

In general, there are two distinct human hazards presented by radiation, those of external and internal radiation exposure External radiation exposure is due mainly to gamma ray emissions from radioactive decay Although plutonium does produce x- and gamma rays, they are very weak and only comprise a small percentage of the total energy emitted A comparison of the unit risk estimate values for external exposure versus internal exposure is provided in Table B 1, and indicates that the inhalation and ingestion pathways produce the most significant degree of risk Therefore, this risk assessment does not consider external radiation exposure as a hazard from Sites 200-202 Plutonium does, however, present an internal radiation hazard, primarily from inhalation and ingestion The inhalation of plutonium can lead to the deposition and retention of radioactivity in the lung, and produce continual, localized internal irradiation of lung and other body tissues for extended periods of time Direct ingestion of contaminated soil, and ingestion of contaminated foodstuffs is another pathway that can contribute to deposition and retention of radionuclides in the body

The following summarizes the important properties of plutonium^{239}

Physical half-life 2 44x10^{4} years
Sources used in nuclear weapons
Principal modes and energies of decay in million electron volts (MeV) alpha 5 06 (11%) 5 13 (17%) 5.15 (73%)

Special chemical characteristics member of the actinide series of rare-earth elements Forms insoluble fluoride, hydroxides, and oxides Oxidizes rapidly on exposure to air to form plutonium dioxide (PuO_2)

Critical Organs bone and liver

Atomic number 94
Physical form silvery-white metal
Melting point 680°C

Plutonium is primarily an alpha particle emitter An alpha particle is essentially a helium nucleus without orbital electrons It is composed of two protons and two neutrons with a charge of plus two Since these alpha particles have a relatively large mass and +2 charge, they react strongly with matter, and create a large amount of ionization in a very short distance However, even alpha particles with the high kinetic energies of plutonium travel only about 1 6 in (4 cm) in air, and can be stopped by a piece of paper, or the outermost layer of dead skin Alpha particles therefore do not present an external exposure hazard These same properties do however produce much more cellular damage than an equivalent amount of gamma energy, if both alpha and gamma are internally deposited The range of penetration of a plutonium alpha particle in tissue is approximately 100 micrometers (um) ($3\ 9x10^{3}$ in), indicating that an alpha particle retained in the body will deposit 100 percent of its ionizing radiation to localized tissue The concepts developed in this section describe the various ways plutonium can enter the body (exposure routes), and the relative risk of each mode of uptake For the purposes of this qualitative risk assessment as well as the generic risk assessment in Appendix C, it is assumed that the insoluble form of plutonium, plutonium dioxide ($Pu0_2$), will be the predominant radionuclide available for biological uptake This assumption is based on a variety of studies (Eisenbud, 1987, Bair, 1973, McClellan, 1972, Romney, 1972) that indicate plutonium will oxidize in an environmental setting and thus form insoluble compounds. Although only the EPA Health Effects Assessment Summary Tables (HEAST) were used for this qualitative assessment, more sophisticated sources may be used during the quantitative risk assessment

4 4 SOURCE TERM

For purposes of this risk assessment, the potential source term for Sites 200-202 is taken as the plutonium-contaminated reservoir/lake sediments within the three reservoirs The isotopic

composition of plutonium at the RFP is shown in Table 4 1 An examination of the available data for Sites 200-202 has been performed and is presented in Appendix A The examination indicates that in some cases, the quantitation limits and detection limits for plutonium were not included in the referenced documents It is believed that most of the published data have not been through a rigid quality assurance/quality control (QA/QC) analysis It is also evident that sampling procedures for all media have differed between various sampling agencies In addition, there is some uncertainty as to the extent of the plutonium contamination Both the extent and the magnitude of the source term will be characterized during the RFI/RI activities Because of these uncertainties, a numerical value cannot be assigned to the source term at Sites 200-202 with any certainty Analysis of existing data indicate that the plutonium concentrations in sediment average less than 0 5 pCi/g, and that the highest value measured was less than 5 pCi/g Tables 2 1 and 2 2 summarize the ranges and averages of the data from the documents reviewed in Appendix A The reader may compare the values found in Tables 2 1 and 2 2 to the calculated risk from exposure to 0 01, 0 1, 1 0 and 10 pCi/g, found in Appendix C and also compare these values to the existing soil background level of plutonium found throughout the United States of 0 2 pCi/g (EPA, 1990) Section 4 10 discusses additional data needed for a reliable determination of Sites 200-202 source term to support a quantitative risk assessment

4 5 POTENTIAL EXPOSURE PATHWAYS

The identification and assessment of potential exposure pathways is accomplished by characterizing the potential contaminant release mechanisms which may contribute to a completed exposure pathway to human and environmental receptors The release mechanism analysis evaluates the possible migration of the chemicals of concern, taking into account their physical and chemical properties that affect environmental fate in the various site media Certain site characteristics such as hydrogeology, meteorology, soil organic carbon, climate, and vegetative cover, etc may also have a significant influence on the migration potential

A preliminary description of the exposure pathway should answer the following questions

- Where, when and how will the release of the toxicant occur?
- What is in the immediate vicinity of the release?
- What is the quantity, physical state, and chemical identity of the released material?

TABLE 4.1

ISOTOPIC COMPOSITION OF ROCKY FLATS PLUTONIUM

Isotope	Relative Weight (percent)	Specific Alpha Activity (Curies/gram)	Specific Beta Activity (Curies/gram)	Relative[a] Activity (Curies/gram)
Pu-238	0 01	17 1	—	0 00171
Pu-239	93 79	0 0622	—	0 05834
Pu-240	5 80	0 228	—	0 01322
Pu-241	0 36	—	103 5	0.37260
Pu-242	0 03	0 00393	—	$1\ 18 \times 10^{-6}$
Am-241	—[b]	3 42	—	—

Source Rockwell, 1985b

[a] Relative activity is obtained by multiplying the percent by weight by the specific activity

Total activity for the plutonium isotopes is

Alpha 0 0732 curies/gram
Alpha plus Beta 0 446 curies/gram

[b] Am-241 daughter from decay of Pu-241

Again, an examination of the data presented in Appendix A concludes that the information necessary to perform a rigorous exposure pathway characterization was not contained in any of the existing reports Although answers to the above questions cannot be obtained from the existing information, it is possible to identify likely site-specific release mechanisms and transport media based on the generic risk assessment presented in Appendix C Characterization of all potential exposure pathways will be performed during the RFI/RI activities

4 5 1 Potential Exposure Pathways at Sites 200-202

Figure 3-2 identifies all of the various potential transport media which exist at Sites 200-202, along with their associated primary and secondary release mechanisms Section 3 0 also describes plutonium fate and mobility in the environment, and concludes that for conditions at Sites 200-202, plutonium is highly insoluble in ground water and surface water, and bonds strongly to the bottom sediments As stated previously, a completed exposure pathway must exist for a hazard to be conveyed to the receptor Judgements based on existing data indicate that many of the potential transport media and release mechanisms identified thus far do not form a completed pathway, and therefore do not pose a risk to human health The only credible completed exposure pathway based on current land use for Sites 200-202 is shown in Figure 4-1 Although other pathways are addressed in this report (and will be characterized in the RFI/RI) they are not considered in the determination of qualitative risk It is possible that the ingestion of contaminated soils, and suspended plutonium sediments in water may provide a completed pathway, but as shown in Appendix C, their contribution is negligible when compared to the risk of inhalation

Primary and secondary release mechanisms for the current land use scenario are grouped with transport media (Table 4 2) to determine their probability of transporting plutonium in the environment based on the following probability ranking

1 High -- historic records or physical characteristics of Sites 200-202 indicate that plutonium has a high probability of being released by this mechanism or transported by this media

2 Moderate -- a possibility exists that plutonium may be released by this mechanism or transported by this media (airborne, fugitive dust, surface runoff)

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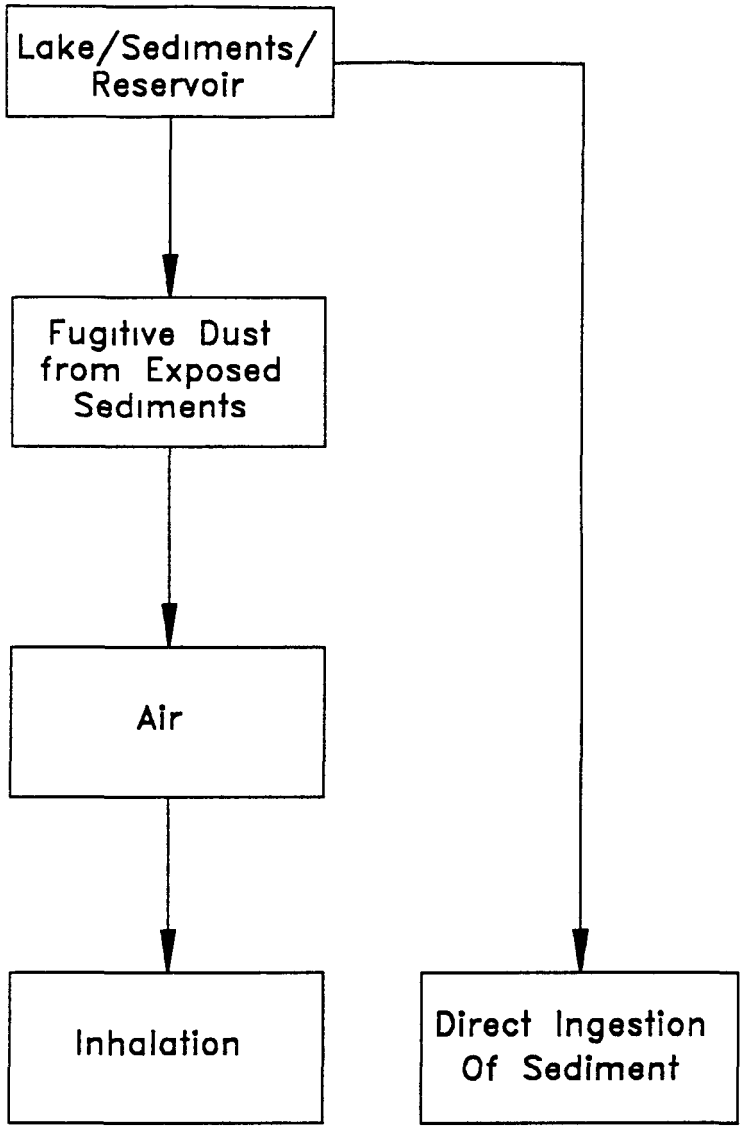


FIGURE 4-1

COMPLETED EXPOSURE PATHWAYS,
SITES 200-202
QUALITATIVE RISK
ASSESSMENT

TABLE 4.2

PROBABILITY OF OCCURRENCE AND QUALITATIVE RISK SITES 200-202, ROCKY FLATS PLANT

Primary Release Mechanism	Probability of Occurrence of Contaminant in Media	Transport Medium	Secondary Release Mechanism	Probability of Occurrence of Contaminant in Media	Importance to Risk Assessment	Magnitude of Qualitative Risk
Fugitive dust from exposed sediments	low-moderate	Air	Airborne settled dust-plant settled dust-soil settled dust-water	low-moderate low-moderate low-moderate negligible	critical critical critical marginal	low-negligible low-negligible low-negligible negligible
Wind stripping of water	negligible	Air	airborne	negligible	marginal	negligible
Reservoir discharge	low-negligible	Surface Water	Biotic Uptake Deposition Irrigation Infiltration Fugitive dust erosion	negligible negligible negligible negligible negligible	marginal marginal marginal marginal marginal	negligible negligible negligible negligible
Drinking water withdrawal	negligible	Treatment Plant	tap water	negligible	marginal	negligible
Ground water infiltration	negligible	Ground Water	seepage pumpage transfer to surface water	negligible negligible negligible	marginal marginal marginal	negligible negligible negligible negligible
Biotic uptake	negligible	Biota	biodegradation	negligible	marginal	negligible

3 Low -- the likelihood is that this release mechanism or transport media does not provide any significant possibility of release or transport in the environment (fugitive dust)

4 Negligible -- all historic data and physical characteristics of plutonium indicate that this is not a credible release mechanism or transport pathway for plutonium (ground water, surface water, biotic uptake)

The following sections discuss some of the release mechanisms and transport media in more detail

4 5 1 1 Identification of Release Mechanisms

The potential exposure pathways are identified in the pathway analysis as shown in Figure 3-2

The potential primary release mechanisms include

- Fugitive dust (wind erosion)
- Direct contact through recreational use
- Direct fugitive dust from sediments
- Wind stripping of water
- Reservoir discharge
- Drinking water withdrawal
- Infiltration/percolation
- Biotic uptake

The potential secondary release mechanisms include

- Settled dust - plants
- Settled dust - soil (leading to possible airborne dust)
- Settled dust - water
- Biotic uptake of surface water
- Surface water deposition
- Surface water irrigation
- Surface water infiltration
- Surface water evaporation/lowering (leading to possible airborne sediments)
- Ground water seepage
- Ground water pumpage
- Drinking water
- Precipitates from treatment plant

4 5 1 2 Identification of Transport Media

A physical examination of Sites 200-202 and an historical review of the records for the site indicate that the primary transport media for plutonium is the fugitive dust release from exposed

sediments Numerous possible primary release mechanisms are listed above, but it is the fugitive dust release mechanism that causes the greatest impact on the secondary transport media of air

Figure 4-1 does indicate that there is also a potential for direct sediment ingestion However, as shown in Appendix C, the ingestion pathway contribution is negligible when compared to the inhalation route Therefore it is concluded that fugitive dust causes the greatest potential human impact

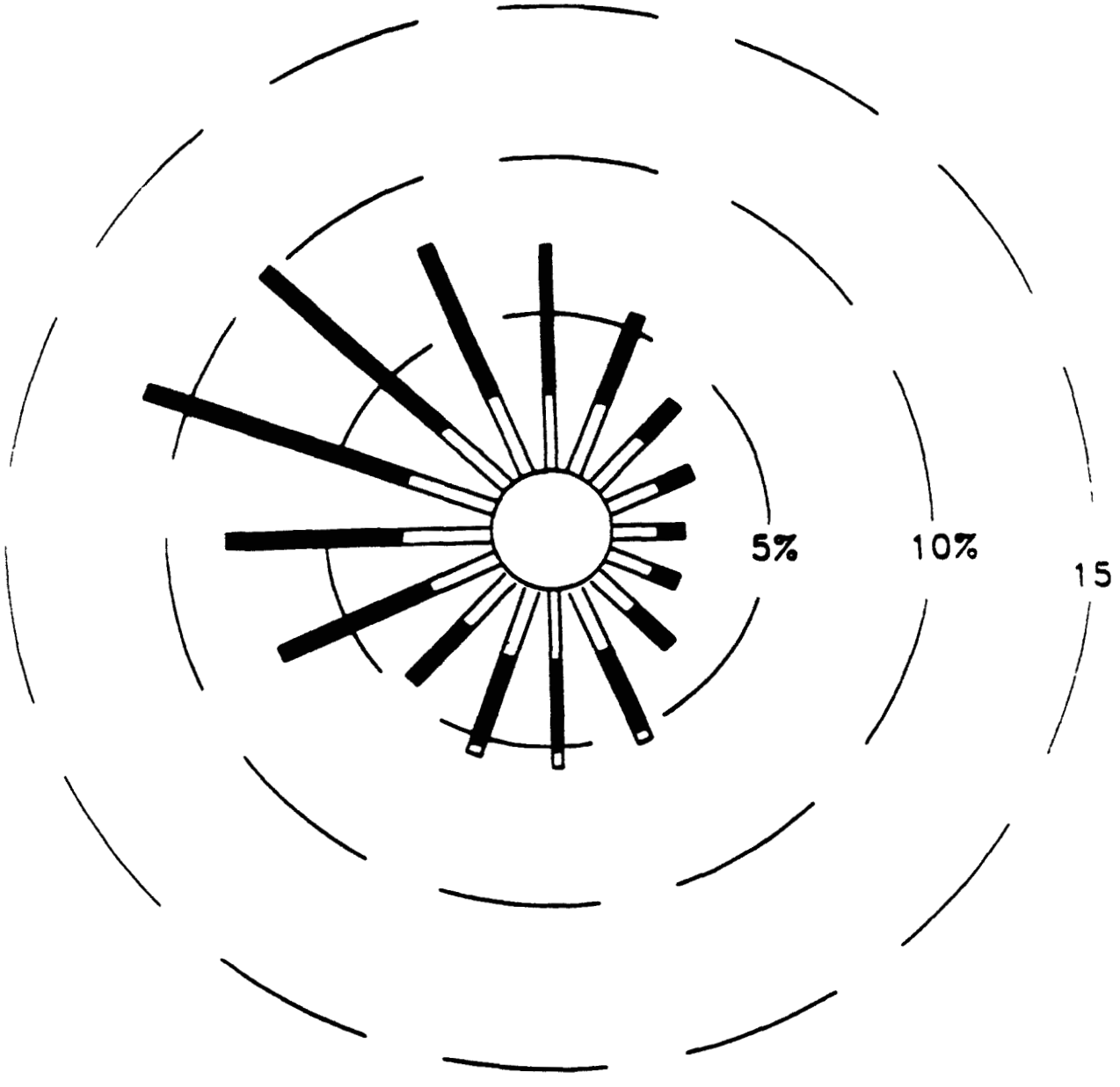
For Sites 200-202, the potential secondary transport media for plutonium includes surface water, groundwater, treatment plant effluent and precipitates, and biotic uptake Figures 4-2 and 4-3 provide some indication of the populations which are downwind of Sites 200-202, and which could potentially be impacted by fugitive dust releases The RFI/RI will address the populations at risk in detail.

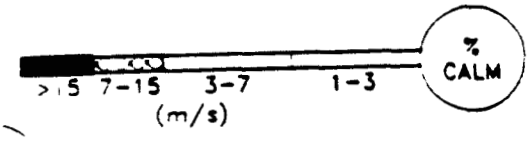
The following discussion provides a more detailed description of the various transport media and release mechanisms which are of primary interest As has been stated, all of the potential exposure pathways will be evaluated in the scheduled RFI/RI activities

Soil Reentrainment

The general principles of atmospheric fate and mobility of plutonium are described in Section 3 2 2 However, a further explanation of atmospheric transport parameters is offered in this section because inhalation and ingestion of plutonium particles from reentrained sediments is considered to be the most probable means of human exposure adjacent to Sites 200-202 The principal mode of transport of plutonium particles is direct airborne movement from the Sites 200-202 exposed sediments, either by uplift or particle impact, or by resuspension of previously deposited small particles by wind action or other disturbances (EPA, 1990b)

Direct action of air moving past a particle may exert enough force to accelerate the particle, causing it to roll along the surface or to be lifted up and moved in the air stream A second mechanism of initiating particle movement can also be initiated through the impact of airborne particles with particles on the ground Particles on a solid surface which have chemical and





5~ Frequency of Occurrence

OVERLAY FIG 4-2

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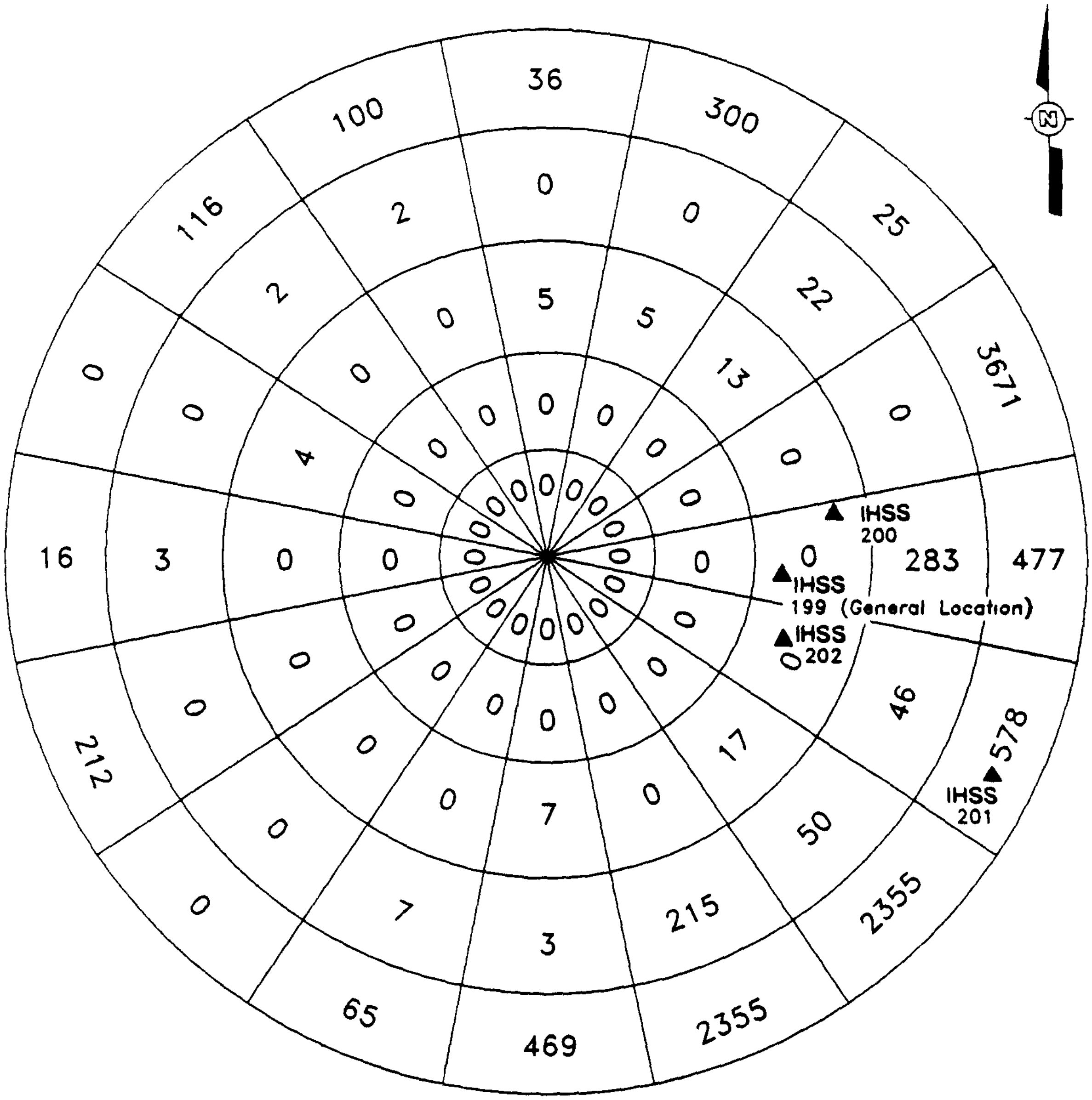


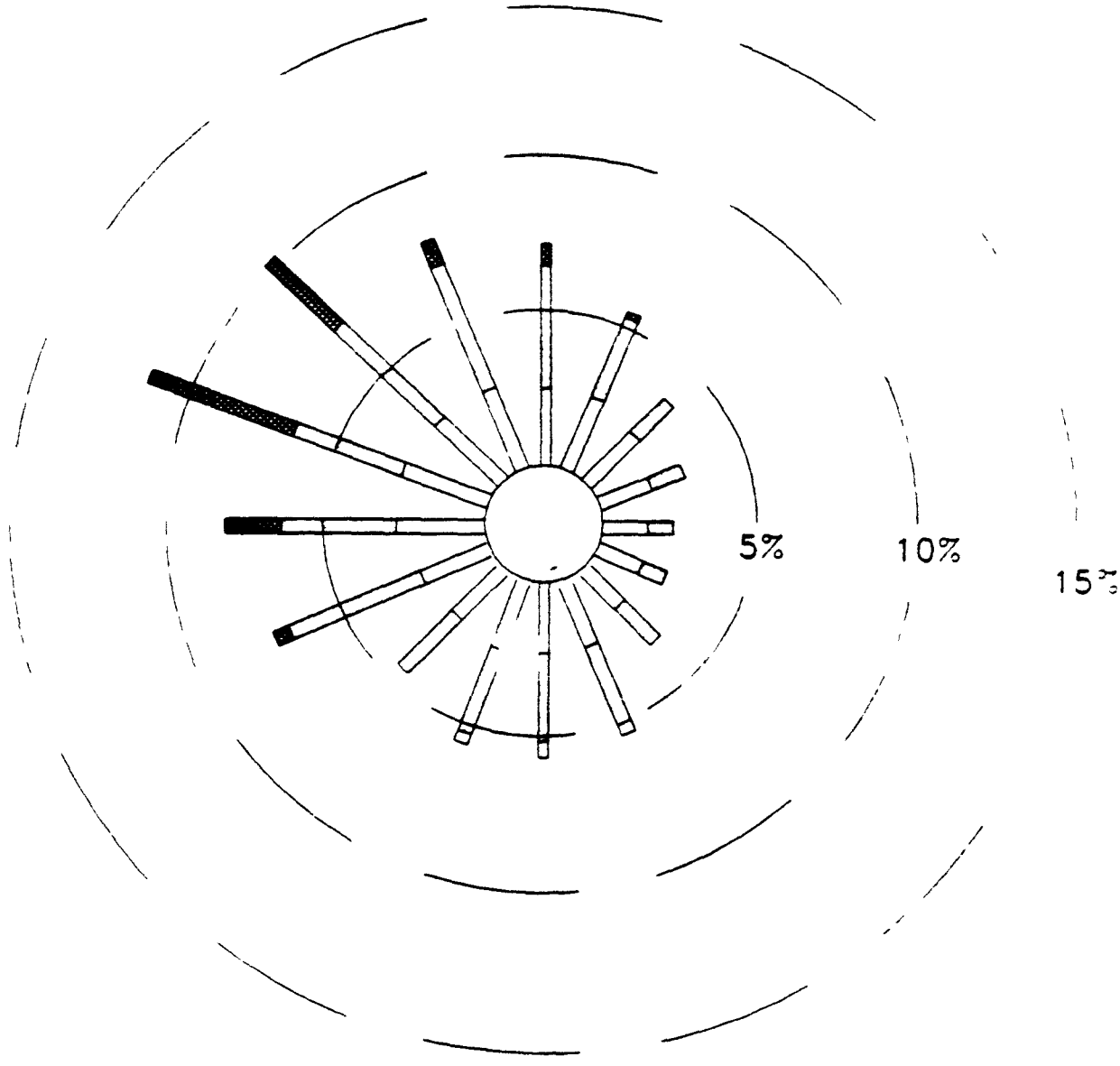
Miles	Sector Name
0-1	Sector 1
1-2	Sector 2
2-3	Sector 3
3-4	Sector 4
4-5	Sector 5

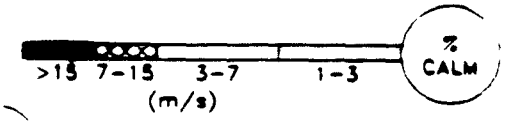
[65] Number of persons living in sector

FIGURE 4-2

WIND ROSE AND 1989 POPULATION, 0-5 MILE SECTORS ROCKY FLATS PLANT

REFERENCE FIGURE 2-1 DOE 1989 POPULATION ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT





5% Frequency of Occurrence

OVERLAY FIGURE 4-3

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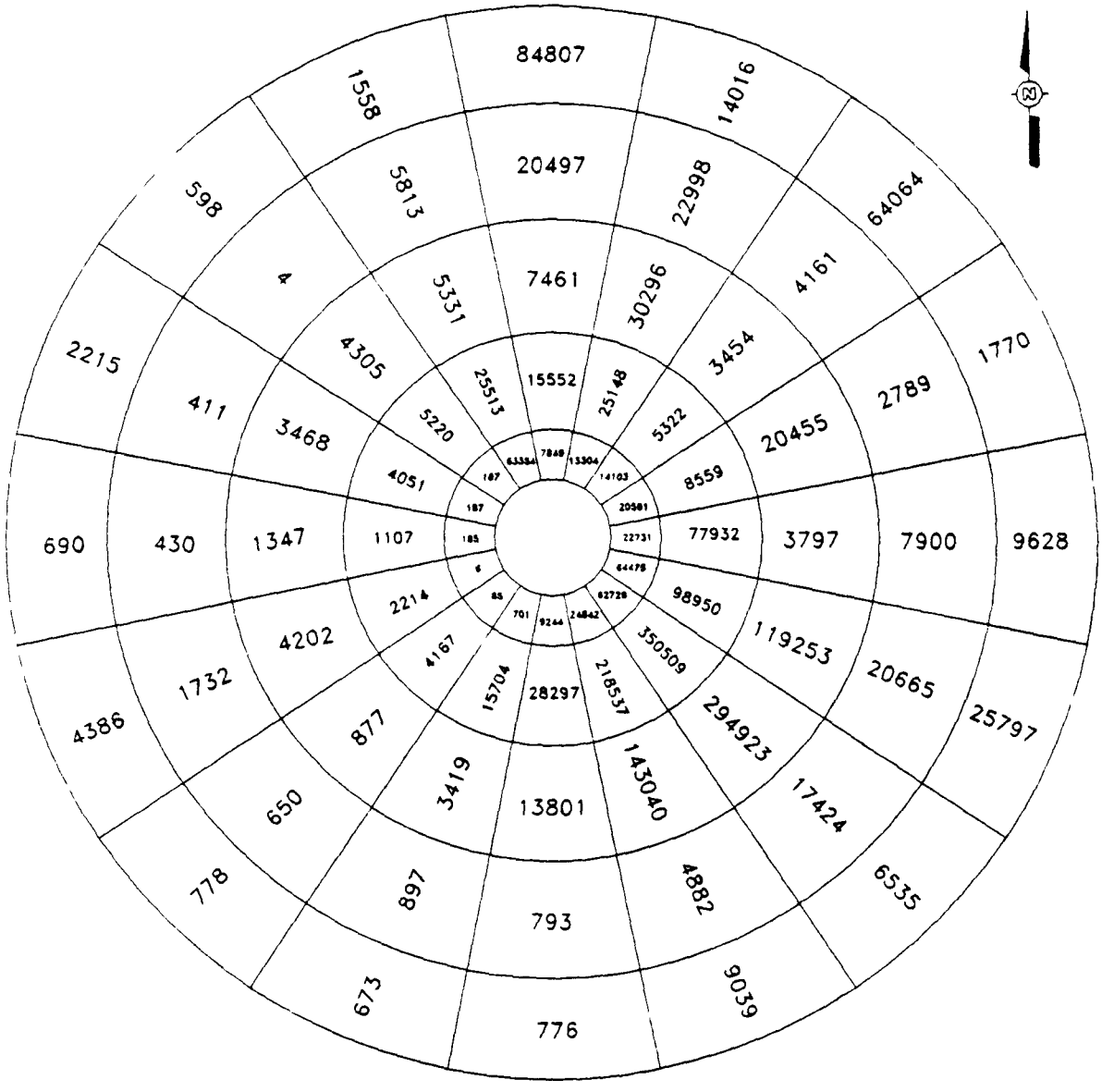

Miles	Sector Name
5–10	Sector 10
10–20	Sector 20
20–30	Sector 30
30–40	Sector 40
40–50	Sector 50

65
Number of persons living in sector

FIGURE 4-3

WIND ROSE AND 1989 POPULATION, 10-50 MILE SECTORS ROCKY FLATS PLANT

REFERENCE FIGURE 2-4 DOE 1989 POPULATION ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT

physical properties different from the base material have adhesive contact to the substrate For resuspension to occur with this scenario, the force on the particle must be equal to or greater than the force holding the particle to the surface Several factors are known to influence particle cohesion

- particle material
- size
- shape
- surface roughness
- relative humidity of the ambient air
- presence of electrostatic charge
- nature and physical characteristics of the substrate

The primary meteorological factors which influence the suspension of material from ground deposits are wind and ground surface moisture The amount of material that can be carried in the air currents is dependent on the density, velocity, and viscosity of the air Particles that are dislodged from the ground surface can then move in three ways suspension, saltation, and surface creep Suspension occurs when upward wind eddies counteract free fall, allowing transport of the particle at the average forward speed of the wind. These particles are generally less than 0 05 millimeter (mm) in diameter and are redeposited via rainout or gravity after the wind subsides Particles between 0 05 mm and 1 0 mm in diameter move by a series of short bounces called saltation Larger particles greater than 1 0 mm in diameter can roll and/or slide along the surface in what is called surface creep (EPA, 1990b) Particle movement predominantly occurs by saltation

For purposes of this qualitative assessment, it is assumed that any free plutonium in the reservoir sediments has been subject to weathering and aging Previous RFP studies (Krey and Hardy, 1970, Whicker et al , 1974) and general textbooks (Wick, 1967) support this statement concerning the weathering of plutonium in the environment Additional studies are needed as part of the scheduled RFI/RI activities to verify this assumption Among the parameters which most influence the movement of soil by wind are the space and time variation of the sediment particle size distribution Considering the lack of data on plutonium distribution in the reservoir sediments, a conservative assumption for both the qualitative and generic risk assessment is that all airborne plutonium generated by exposed sediments is of a respirable particle size

The area of highest concentration of plutonium in Great Western Reservoir and Standley Lake appears to be in the deep water areas where the greatest sedimentation rate has occurred The areas of minimum plutonium concentrations seems to be the shallow water and shoreline areas These shallow water and shoreline areas have the greatest potential to dry up and allow for potential reentrainment of sediments into the atmosphere There is little doubt that fugitive dust is generated from the shoreline sediments at these reservoirs However, since the plutonium concentrations in these areas are generally at or below CDH guidance concentrations for surface soils, its risk via the inhalation pathway is judged to be minimal Based on the information presented in this document, the following statements can be made

1 The location of highest plutonium concentrations tend to be in the deepest part of the reservoirs This conclusion may or may not be true for Mower Reservoir

2. The location of the lowest plutonium concentrations tend to be along the shoreline and shallow water areas of the reservoirs These areas are the most likely to be subject to drying and reentrainment of sediments into the air

3 Sediment sampling results indicate that a discrete contamination layer exists at both Great Western Reservoir and Standley Lake, but has been buried by subsequent sedimentation Sampling results indicated however, that there is plutonium located at the surface of the sediment

4 The plutonium is strongly bound to the sediments and will not easily resolubilize

5 It is possible that the reservoir levels may drop, exposing the deeper plutonium-containing sediments to drying, however, in general, this exposed beach area would produce a crusty, platelike surface which would require pulverization for the sediments to become airborne It is plausible that vehicular traffic could produce this pulverization If reservoir levels remain low, long-term weathering could also eventually provide means for reentrainment

Based on the current use of the reservoirs, the low concentrations of plutonium in the sediments, and its general lack of mobility in the environment, it is judged that the no-action alternative for the sediment-inhalation exposure pathway presents a low risk to the public

Plutonium Uptake in the Food Chain

As described in Section 3 0, plutonium forms relatively insoluble compounds in the environment and is therefore not generally considered ecologically mobile (Eisenbud, 1987) Since plutonium

has no known biological function, it can only be passively incorporated into organisms, mainly by physical processes such as surface contact, inhalation, and ingestion of plutonium adsorbed to the surfaces of plants and zooplankton The generic risk assessment in Appendix C does take into account food chain transfer and foliar deposition of plutonium leading to human uptake The Standley Lake fish study (Appendix D, Document D-11) indicated that no bioconcentration and bioaccumulation is occurring in fish species at the reservoir

Ground Water and Surface Water

With regard to water quality, the need for potential site remediation should be based largely on the evaluation of current and potential risks to the public who may use the surface or underground aquifer as a source of drinking water A key evaluation criterion in selecting remedial measures at Sites 200-202 should be the extent to which alternatives mitigate off-site exposure via the ground water/surface water pathway if in fact exposure is occurring All data reviewed to this point indicates that the ground water/surface water interactions in and around all three reservoirs should not result in any detectable amount of plutonium in ground water This statement is based on historic data from numerous RFP on-site wells which are located in areas of documented contaminated pond leakage. With one exception, in no case has there been detectable concentrations of plutonium in ground water If no impact is seen in this worst-case situation it is highly unlikely that the reservoir sediment interactions will impact ground water This judgment will not be used to eliminate potential exposure pathway from evaluation during the scheduled RFI/RI activities

The surface water quality monitoring results indicate that plutonium concentrations are far below regulatory limits for the reservoirs (Section 2 0) It is important to note that these measured concentrations are just above the analytical detection limit, and well below the EPA or CDH risk-based limits for drinking water In the absence of site-specific data (which will be collected during the RFI/RI), only a relative measure of hypothetical risk may be discussed for the ground water/surface water exposure pathway. Based on the information presented in this document, the following conclusions can be drawn

1 The sediments in all three reservoirs contribute little or no plutonium to the ground water/surface water

2 All sampling data from the reservoirs indicate that no bioaccumulation of plutonium is occurring in water plants, phytoplankton or fish

3 Plutonium rapidly and almost irreversibly attaches itself to clay sediments, and there is no evidence of post-depositional migration of plutonium through the sediment. This leads the conclusion that plutonium is not readily available for remixing in the water, even under lake turnover conditions.

4 All surface water quality monitoring data for plutonium in and around the three reservoirs are well below CDH and EPA regulatory standards

5 Most importantly for evaluating receptor risk, tap water samples were taken from the communities that utilize the reservoirs as a source of drinking water The results of this monitoring indicate concentrations of plutonium in drinking water that are just above or below the analytical detection limit, and well below CDH and EPA regulatory standards

Based on these conditions, it is determined that the no-action alternative for the ground water/surface water pathway at reservoirs presents a negligible hazard to the public

4 6 EXPOSURE ROUTES FOR CURRENT AND FUTURE LAND USE CONDITIONS

The three exposure routes (routes of entry) which can lead to internal radiation exposure are inhalation, ingestion, and dermal contact The two primary exposure routes of plutonium uptake that could most likely lead to internal radiation exposure are the inhalation and ingestion of radioactive materials Dermal contact is not considered a significant exposure route (Section 4 3)

The estimation of organ burden and exposure, as well as of the resulting dose rates and doses, due to uptake by these pathways is based on the use of mathematical models which depend on many parameters International Commission on Radiation Protection (ICRP) publications ICRP 30 (ICRP, 1988a), ICRP 31 (ICRP, 1980), and ICRP 48 (ICRP, 1988b) provide the criteria necessary to calculate the committed effective dose equivalent for both occupational workers and the general public This section will show that the magnitude of the dermal contact/ingestion pathway is insignificant when compared to inhalation

4 6 1 Inhalation

The inhalation of an aerosol carrying radionuclides is a potential mechanism for damage to the respiratory tract as well as a possible pathway for the translocation of inhaled radioactive material to other reference organs The complexity of the biological phenomena which govern transmission and elimination of such material complicates the assessment of potential health effects due to inhalation of radioactive material Factors which must be included are

1 The fractional deposition of inhaled material in the respiratory tract depends on properties of the aerosol size and mass distribution, chemical form, and charge, as well as on the breathing rate and such physiological characteristics of the lung as its surface properties and configuration For the purposes of this qualitative risk assessment, it is assumed that 100 percent of the plutonium in dust is available for uptake.

2 The duration and extent of the exposure depends on the biological and physical mechanisms which transport the deposited material and its decay products within the body These include the various clearance paths, the nuclide half-lives, the chemical form, the solubility, and the degree of retention in each organ of interest

3 The dose depends on the duration, of the activity of both parent and daughter radionuclides in the organ, the organ mass, the emitted energy of each nuclide, and the fraction of that energy absorbed by the organ tissues

The inhalation mode of exposure has long been recognized as being of major importance for radioactive materials The model used in Appendix C to calculate a generic plutonium risk assessment for current use indicates that for conservative assumptions, the contribution of the inhalation pathway comprises 97 percent of the total risk This route provides a direct pathway for alpha particles to enter the sensitive organ which is the lung The lung is the organ of primary concern when assessing the risks from plutonium in soil (EPA, 1990b)

When inhaled, plutonium is retained in the lung with an effective half-life that varies from hundreds of days for plutonium oxides (Y class) to tens of days for more soluble forms (W class) A significant portion of the insoluble plutonium oxide that leaves the lung is translocated to the tracheobronchial lymph nodes Inhaled soluble plutonium is translocated to the liver and skeleton where it is very strongly retained (Bair, 1973) This is in contrast to the ingestion pathway, where the gut wall acts as a barrier to plutonium absorbed by blood

Inhalation is the most common pathway by which plutonium can cross the barriers of the body and penetrate into and across living cells The aerodynamic particle size of the aerosol, which accounts for not only the sizes of the particles but also their density and shape, determines the fractional deposition and sites of deposition in the respiratory tract The bioavailability of plutonium adsorbed to particles often depends on this aerodynamic particle size Particles with a diameter greater than 5 microns usually become imbedded in the mucous of the pharynx, trachea, or bronchi The mucous is swept up the respiratory tract and swallowed Therefore, the residence time of inhaled plutonium in the nasopharyngeal and tracheo-bronchial regions is short. The absorption efficiency of these large particles depends on the gastrointestinal absorption efficiency, which is extremely low for plutonium (Section 4 6 2) Consequently, inhaled particles that are subsequently ingested reduce the magnitude of the inhalation pathway The subsequent rates and routes of clearance, the translocation to, deposition in, and rate of clearance from other tissues, and the excretion in urine and feces of plutonium depend on particle size, solubility, density, shape and other physicochemical characteristics of the plutonium aerosol The radiation dose delivered from an inhaled radionuclide is a function of the transportability of the particular chemical form from the lung to other organs of the body Chemical forms of radionuclides are classified as Class D, W, or Y from most transportable to least transportable, respectively The ICRP has determined the solubility class for various plutonium compounds (ICRP, 1988a) These are

- Class D (days) - no plutonium compounds
- Class W (weeks) - all plutonium compounds except oxides
- Class Y (years) - oxides (PuO_2)

Environmental sources and airborne releases of plutonium are likely to be in the oxide form (EPA, 1990b) Class Y plutonium refers to the solubility and body retention of the radionuclide This class is insoluble in the body and, if breathed in, tends to be retained in the lungs for months to years As stated previously, PuO_2 is considered to be insoluble in the body, and thus is classified as Class Y plutonium.

4 6 2 Ingestion

The ingestion of radioactive material (soil, water) represents another pathway by which radioactivity may be transferred internally to blood and, subsequently, to other organs While

a description of this pathway is simpler than for inhalation, due to the direct deposition of the ingested material into the GI tract, evaluation of the balance of the biological-physical processes involved is affected by the same uncertainties of biological parameters as were discussed for the inhalation model In the ingestion model the critical transfer mechanism is the absorption of radioactive material into the systemic blood from the small intestine, however, the gastrointestinal tract provides a substantial barrier to the uptake of plutonium ingested with food or water In adult animals less than 0 01 percent of ingested plutonium is absorbed from the intestines (ICRP, 1988b) Inhaled plutonium will also be cleared from the lungs to the gastrointestinal tract, so gastrointestinal absorption is a consideration Values for the fraction, f_1 (GI absorption factor), of ingested radioactivity transferred to blood have been studied in animals and to a limited extent, are still subject to large uncertainties which strongly affect projected doses to the reference internal organ The ICRP lists an f_1 value of $1x10^{-5}$ for oxides of plutonium, an f_1 value of $1x10^{-4}$ for nitrates of plutonium, and an f_1 value of $1x10^{-3}$ for all other forms of plutonium (ICRP, 1988a) This indicates that the ingested plutonium will not easily transfer to other body compartments The HEAST values listed in Table B 1 indicate that the EPA is using an f, value of 1×10^{-4} for the oxides of plutonium

For the generic risk assessment (Appendix C), the ingestion pathway becomes more significant, and in fact may contribute the greatest percentage of risk This contribution is due to utilizing reasonable maximum exposure scenarios concerning resuspension of plutonium into the drinking water supply

4 6 3 Dermal Contact

Plutonium-239 and plutonium-240 are alpha emitters and hence only present a biological hazard if they are transferred into a biological system, however, dermal absorption is not a major route of exposure (EPA, 1990b) The dermal contact human transfer pathway for plutonium would involve skin contamination and subsequent transfer into the body through an open wound or by ingestion Unbroken skin has been shown to be an effective barrier to the penetration of plutonium, and dermal absorption coefficients cited in the literature are on the order of $5x10^{-5}$ (NRC, 1988) It is highly unlikely that soluble plutonium is present in exposed sediments at Sites 200-202 in concentrations that would lead to transfer through an open wound by skin

contamination Since the GI absorption factor is 1.0×10^{-5} for class Y (insoluble) plutonium, human bio-uptake of plutonium soils by the dermal contact pathway and subsequent GI absorption is not plausible

4.7 RISK CHARACTERIZATION

This qualitative risk assessment is a systematic identification of potential hazards of events that could result in undesirable consequences, and is inherently basically subjective The main disadvantage of this qualitative approach is that it is difficult to make specific numerical comparisons among the risks of different events or scenarios However, as shown in Table 4 1, hazards can still be grouped by relative importance to the risk assessment (i e , critical, marginal) and linked by magnitude of qualitative risk (i e , high, moderate, low, negligible) Pathways and release mechanisms that are classified as having critical importance to the risk assessment would have a high probability of impacting a human receptor Those that have a marginal importance have a very low probability of impacting a human receptor These groupings, coupled with the risk evaluation presented in Appendix C, also can be used to indicate that there is not any imminent threat to human health from Sites 200-202

4.7.1 Risk Characterization Process

The risk characterization presented here evaluates the relative occurrence of plutonium in each media, its likelihood for transport to other media, and its likelihood to impact a human receptor The concepts developed in preceding sections are utilized to determine the magnitude of risk (using existing information) based on the following ranking.

1 High -- A significant potential hazard to human health exists based on historical data, physical characteristics and/or present conditions

2 Moderate -- maximum credible assumptions of release mechanisms and exposure pathways, it is possible that plutonium will be measured at the receptor point

3 Low -- It is highly unlikely that a hazard to human health exists, using maximum credible assumptions of release mechanisms and exposure pathways combined with historical data, the physical characteristics of plutonium transport and present conditions

4 Negligible -- The release mechanisms and completed exposure pathways are essentially non-existant, therefore there is no risk to human health

4 7 2 Physical Model

Providing a reasonable estimate of internal radiation doses due to inhalation and ingestion requires that a consistent model for both the respiratory and gastrointestinal tracts be employed While a large amount of theoretical and experimental work on such models has been done, the most widely accepted models that provide reasonable estimates of internal radiation doses have been those developed by members of the respective ICRP working groups

The proposed ICRP Task Group on Lung Dynamics (TGLD) model for the respiratory tract has been well documented Parameters suggested for use in the model have been extensively reviewed and, to some extent, improved in ICRP publications (ICRP, 1988b, ICRP, 1980) The ICRP TGLD proposed model comprises three major respiratory compartments the nasopharyngeal, the tracheobronchial, and the pulmonary Each of these major compartments is divided into subcompartments corresponding to various transfer mechanisms, which are treated as essentially independent processes In addition, the associated lymph nodes are appended to the pulmonary compartment in one of the transfer chains Direct deposition through inhalation occurs to the three major compartments, with the fractional deposition in each being a function of the aerosol properties Subsequent transfer and/or clearance is governed by parameters specified for each subcompartment

For the calculation of soil/water ingestion, the ICRP gastrointestinal tract model can also be used to determine internal exposure The model comprises a four-compartment tract consisting of the stomach, small intestine, and lower and upper large intestine

4 7 3 Risk From All Modes of Exposure

The chemical forms of plutonium found in the off-site sediments at Sites 200-202 are highly insoluble both in the environment and in the human body Based on a review of exposure pathways and routes it appears that for the current use scenario, the potential for human uptake is negligible and poses a very low potential risk pathway in the qualitative model Developing these concepts in tabular form, biological uptake mechanisms from all release pathways can be ranked from the most likely to the least likely for the current and future land use scenario

Exposure Route

- Inhalation
- Direct ingestion of soils
- Inhalation then ingestion
- Ingestion of drinking water
- Bioaccumulation
- Dermal contact

The last two routes are considered negligible from a risk standpoint based on current data Appendix C utilizes reasonable maximum exposure assumptions to look at potential risk via the pathways listed above

A qualitative comparison of pathway specific risk is provided by the EPA (EPA, 1990b) The EPA has developed the following media-specific concentration-based unit risk factors for age-averaged lifetime excess total cancer per unit daily intake (exposure for 70 years) of Class Y Plutonium-239

Risk per Unit Concentration[1]		
Air 1 pCi/m^3	Drinking Water 1 pCi/l	Soil Ingestion 1 pCi/g
2.6×10^{2}	1.6×10^{6}	8.4×10^{8}

[1] The media-specific risks are based on standard man (155 pounds [70 kilograms]) intake rates of

- 706 ft^3/day (20 m^3/day) inhaled air
- 0 6 gal/day (2 2 l/day) ingested liquid
- 2.2×10^{-4} lbs/day (0 1 g/day) ingested soil

These values assume that all daily media exposure is derived from contaminated airborne fugitive dust (706 ft^3), surface water/surface runoff (0 6 gal water), and soil (2.2×10^{-4} lbs) and that exposure occurs continuously for a 70-year lifetime In other words, per unit concentration in each media, the unit risk is far greater from inhalation of dust in air than the other two exposures, however, it should be kept in mind that unit concentrations in these media are not comparable in terms of likelihood of occurrence In fact, the generic risk assessment developed

in Appendix C indicates that for the future use residential scenario, the ingestion pathway would contribute the significant percentage of total risk Inhalation has been calculated to be the primary risk for the no action alternatives for current land use

These unit risk factors use the same basic approach as other models (DOE, ICRP), however, the EPA uses the model to derive risk from each type of media These risk factors reinforce the premise that inhalation of plutonium (pCi/m^3) has a much greater risk factor than from ingestion of water (pCi/l) or sediments (soil) (pCi/g) Under current reservoir use, the air pathway from Sites 200-202 produces a negligible risk to the public, therefore it can be inferred that other pathways must also produce a negligible risk

This conclusion will be validated or refuted by calculation of a true site-specific quantitative risk assessment during the RFI/RI.

4 8 APPLICATION OF RISK ASSESSMENT TO EACH RESERVOIR

In the previous sections, the reservoirs have been treated as one unit because of the similarities of sources and pathways The final criteria, that of exposure point, is somewhat dissimilar for the three reservoirs The following sections discuss the source term, exposure pathways, uptake mechanisms, and exposure point for each reservoir separately While various exposure pathways are discounted as part of the qualitative assessment of which pathways are most significant (based on current data and judgement), all of the exposure pathways will be evaluated during the scheduled RFI/RI activities

4 8.1 Great Western Reservoir

Until recently, Walnut Creek emptied into Great Western Reservoir, which is the drinking water source for the City of Broomfield At full capacity, this reservoir is a maximum of 62 ft (19 m) deep and covers 7 $2x10^6$ ft^2 (668,000 m^2) with a volume of 1 $2x10^8$ ft^3 (3,430,000 m^3) Except during periods of heavy rain and runoff the reservoir is not filled to capacity More typically, the reservoir is maintained at about 43 ft (13 m) depth covering an area of 3 $2x10^6$ ft^2 (294,500 m^2) with a volume of 4 $1x10^7$ ft^3 (1,162,000 m^3)

Public access is restricted at the reservoir, and no recreational use of it is allowed. Historical data indicates that the major source of plutonium present in the reservoir is from waste liquid discharges from holding ponds that were transported by tributaries of Walnut Creek This pathway has been eliminated It is unclear if some fraction of the plutonium present in the reservoir sediments is from the airborne pathway produced by the 903 Pad barrel storage area However, this pathway too has been effectively eliminated by institutional controls (construction of an asphalt pad)

4 8.1 1 Surface Water/Tap Water/Ground Water

All of the reservoir, domestic water, and background results are essentially the same within the limits of analytical and sampling variations The results indicate that the sediment in the reservoir is effectively immobilizing the plutonium and preventing its movement into the municipal drinking water The reservoir water passes through a filter plant prior to domestic consumption, further reducing the likelihood that suspended silt containing plutonium could reach a receptor through the drinking water pathway An extensive ground water monitoring system on and around the RFP has been developed The well locations on-site were selected to intercept ground water in areas where potential contamination might be expected Well locations are near holding, evaporation ponds, and creek beds Monitoring wells in the buffer zone along the eastern boundary of the RFP have been sampled, and in no case have plutonium levels above background been detected in any of the wells Although data are not available concerning plutonium transport from Great Western Reservoir surface water/sediments to ground water, it can be inferred that this pathway is not plausible This suggests that soil/sediment is a good medium for removing plutonium from an aqueous media Therefore, since surface water, ground water, and tap water are not sources or transport media for plutonium transport in the environment, the following pathways can be discounted in this qualitative risk assessment

Surface Water → Tap Water
Surface Water → Ground Water
Surface Water → Biotic Uptake
Surface Water → Deposition
Surface Water → Irrigation
Surface Water → Infiltration
Surface Water → Fugitive dust wind erosion
Ground Water → Seepage
Ground Water → Pumpage

4 8 1 2 Reservoir Sediments

Sediment sampling has been performed at Great Western Reservoir on a number of occasions In an EPA study from 1973, peak plutonium sediment concentrations were detected at 4 5 pCi/g, with an average of 1 4 pCi/g in the upper 2 in (5 cm) A Battelle study from 1974 detected plutonium values ranging from 0 01-8 2 pCi/g Rockwell International conducted a sediment study during 1983-84 using two different analyses In this case, peak concentrations were 6 1 pCi/g plutonium in the sediment The highest concentrations of plutonium were found near the inlet of the reservoir and along the dam where the greatest sedimentation rate has also been found This sedimentation rate has effectively buried the greatest concentration of plutonium in a layer approximately 12-15 in (30-38 cm) below the top of the sediment Although at some point the reservoir will be emptied for repair, the qualitative risk of that scenario is not specifically addressed in this document Since it is possible that under normal conditions the reservoir level could drop and expose potentially contaminated shallow water sediments for subsequent fugitive dust wind erosion, this pathway will remain in the qualitative risk assessment

4 8 1 3 Spillway Sediments

The spillway sediment pathway has been examined, and the results indicate that sediments accumulating within the spillway were well below the 0 9 pCi/g (0 03 Bq/g) activity screening level for soils adopted by CDH During periods when the reservoir is not at maximum capacity, the sediment in the spillway is not submerged The location of greatest depth of sediment is near the stop logs of the entrance and sediment accumulation is at minimum at the southeast end of the spillway Although it is possible that these sediments could be the source of fugitive dust, it is not a likely release mechanism for plutonium transport in the environment due to the low probability of plutonium being present in the spillway sediments Therefore the

Lake/Reservoir Sediments → Reservoir Discharge → Surface Water → Fugitive Dust

pathway can be discounted in this qualitative risk assessment

4 8 1 4 Air

No credible scenario exists that could produce an exposure pathway from wind stripping of the surface water As stated previously, although dried reservoir sediments present a possible fugitive dust pathway from wind erosion, the source term (plutonium exposed sediments) is not

present under current conditions Therefore, the following pathway can be discounted in this qualitative risk assessment

Wind Stripping of Water → Air

4 8 2 Standley Lake

Standley Lake is a large body of water 43,000 acre-ft (5,300 hectare-meter) in volume located approximately 2 mi (3 2 km) southeast of RFP's eastern boundary The reservoir is used as a part of the municipal water supply for the cities of Westminster, Northglenn and Thornton, supporting approximately 185,000 persons In addition, the reservoir serves as a recreation area Boating, fishing, swimming, hiking and biking occur in and around the reservoir

Standley Lake receives approximately 96 percent of its water from Clear Creek via an irrigation ditch, a water source that has no history of plutonium transport Woman Creek, an ephemeral stream which also feeds Standley Lake, has been a pathway by which plutonium could migrate to the Lake Historical data indicates that another likely pathway exists from soil erosion within the Woman Creek watershed and windblown plutonium contamination from the 903 Pad area This pathway has been effectively eliminated by institutional controls (construction of an asphalt pad) However, the surface water-soil erosion pathway may conceivably still exist Studies of Standley Lake sediments indicate that contamination is not ongoing, suggesting that the source of plutonium from the Woman Creek watershed was the 903 Pad

4 8 2.1 Surface Water/Tap Water/Ground Water

All of the reservoir, domestic water, and background results are essentially the same within the limits of analytical and sampling variations The results indicate that the sediment in the reservoir is effectively holding the plutonium and preventing its movement into the municipal drinking water. The reservoir water passes through a filter plant prior to domestic consumption, further reducing the likelihood that suspended silt containing plutonium could reach a receptor through the drinking water pathway Extensive ground water monitoring wells on and around the plant site have been developed The well locations on-site were selected to intercept ground water in areas where potential contamination might be expected Well locations are near holding ponds, evaporation ponds, and creek beds Background wells in the buffer zone surrounding the

RFP have also been developed, and in no case has plutonium levels above background been detected in any of the wells This suggests soil/sediment is a good medium for removing plutonium from an aqueous media Although data are not available concerning plutonium transport from Standley Lake surface water/sediments to ground water, it can be inferred that this pathway is not plausible Therefore, since surface water, ground water, and tap water are not release mechanisms for plutonium transport in the environment, the following pathways can be discounted in this qualitative risk assessment

Surface Water → Tap Water
Surface Water → Ground Water
Surface Water → Biotic Uptake
Surface Water → Deposition
Surface Water → Irrigation
Surface Water → Infiltration
Surface Water → Fugitive dust wind erosion
Ground Water → Seepage
Ground Water → Pumpage

4 8 2 2 Lake Sediments

Plutonium concentrations in Standley Lake sediments are much lower than those found at Great Western Reservoir However, this conclusion is based on limited sampling data from numerous studies This source of release to the environment will remain as a potential pathway in the qualitative risk assessment since it is possible that lake levels will decrease, exposing sediments potentially containing plutonium These sediments could then create fugitive dust through wind erosion

4 8 2 3 Air

No credible scenario exists that could produce an exposure pathway from wind stripping of the surface water As stated previously, although dried reservoir sediments present a possible fugitive dust pathway from wind erosion, the source term (plutonium exposed sediments) is not present under current conditions Therefore, the following pathway can be discounted in this qualitative risk assessment·

Wind Stripping of Water → Air

4 8 2 4 Biota

Since Standley Lake is used as a recreational resource for fishing, the CDH analyzed edible fish tissue collected from the lake for the presence of plutonium (Appendix D, Document D-11) Bottom feeders, mid-level and surface predator fish were captured, and in all cases, plutonium concentrations in all species of fish tissue sampled were at or below the lower limit of detection for this analysis Since fish represent the highest level of organisms within the food chain for Standley Lake (excluding bird eating fish and fisherman), the non-detection of plutonium is indicative that bioconcentration is not occurring as one moves up the food chain

4 8 3 Mower Reservoir

Very little documentation exists for Mower Reservoir, but it is used for agricultural purposes and has restricted public access An EPA study was performed during the 1970s, but further data collection is required No recreational use of the reservoir is known to exist Because it is fed by Woman Creek, this reservoir may also have been affected by the surface water contaminants believed to have contributed to plutonium levels in Standley Lake sediments (Section 2 2) Plutonium transported from Site 199 may impact this reservoir However, since current plutonium levels are so low at Site 199, it is felt that any future impact will be negligible from the pathway It has been speculated that concentrations of radionuclides in Mower Reservoir sediments should not exceed levels measured in Great Western Reservoir and Standley Lake Therefore, the same description of possible pathways and their exclusion from the risk model will be restated here

4 8 3 1 Surface Water/Tap Water/Ground Water

All of the reservoir, domestic water, and background results are essentially the same within the limits of analytical and sampling variations. The results indicate that the sediment in the reservoir is effectively holding the plutonium and preventing its movement into the municipal drinking water The reservoir water passes through a filter plant prior to domestic consumption, further reducing the likelihood that suspended silt containing plutonium could reach a receptor through the drinking water pathway Extensive ground water monitoring wells on and around the plant site have been developed The well locations on-site were selected to intercept ground water in areas where potential contamination might be expected Well locations are near holding,

evaporation ponds, and creek beds Background wells in the buffer zone surrounding the RFP have also been developed, and in no case has plutonium levels above background been detected in any of the wells This suggests soil/sediment is a good medium for removing plutonium from an aqueous media Therefore, since surface water, ground water, and tap water are not release mechanisms for plutonium transport in the environment, the following pathways can be discounted in this qualitative risk assessment

Surface Water → Tap Water
Surface Water → Ground Water
Surface Water → Biotic Uptake
Surface Water → Deposition
Surface Water → Irrigation
Surface Water → Infiltration
Surface Water → Fugitive dust wind erosion
Ground Water → Seepage
Ground Water → Pumpage

4 8 3 2 Reservoir Sediments

Limited information is available concerning plutonium concentrations in the sediments The concentrations of radionuclides in these sediments is not expected to exceed those found in Great Western Reservoir or Standley Lake However, this source release will remain as a potential pathway in the qualitative risk assessment since it is possible that reservoir levels will decrease, exposing sediments potentially containing plutonium These sediments could then create fugitive dust through wind erosion

4 8 3 3 Air

No credible scenario exists that could produce an exposure pathway from wind stripping of the surface water As stated previously, although dried reservoir sediments present a possible fugitive dust pathway from wind erosion, the source term (plutonium in exposed sediments) is not present under current conditions. Therefore, the following pathway can be discounted in this qualitative risk assessment

Wind Stripping of Water → Air

4 9 UNCERTAINTIES IN THE RISK EVALUATION

The procedures and inputs used to assess potential human health and environmental risks in this and most such evaluations are subject to a wide variety of uncertainties The five main sources of uncertainty are the following

- Inadequate sample population
- Sampling and analytical methods
- Fate and transport modeling
- Exposure estimation
- Toxicological data and dose response extrapolation

Errors associated with sampling and analysis include inherent errors in laboratory analysis, representativeness of the samples, sampling errors, and heterogeneity of the sample matrix Although QA/QC programs serve to reduce these errors, they cannot eliminate all errors associated with sampling and analysis

4 9 1 Toxicology Uncertainties

Toxicological data errors are also a source of uncertainty The EPA noted this in its guidelines for carcinogenic risk assessment

> "There are major uncertainties in extrapolating both from animals to humans and from high to low doses There are important species differences in uptake, metabolism, and organ distribution of carcinogens, as well as species and strain differences in large site susceptibility Human populations are variable with respect to geographic constitution, diet, occupational and home environment, activity patterns and other cultural factors (EPA, 1986) "

The estimation of exposure requires numerous assumptions to describe the potential exposure situations There are a number of uncertainties regarding the fate and transport of plutonium, the likelihood of exposure, the frequency of contact with contaminated media, the concentration of constituents at exposure points, and the time period of exposure. These assumptions tend to oversimplify actual site conditions There are inherent uncertainties in determining the intake value when combined with toxicological information, to assess risk In this qualitative

assessment, specific assumptions with standardized values were used The major assumptions used in this assessment are as follows

- Constituent concentrations remain constant over the exposure period
- Exposure remains constant over time
- Average concentrations of constituents detected are reasonable estimates of exposure at the exposure point
- Exposed populations remain constant over the exposure period
- No dilution factor for the contaminants is offered, and they are available for 100 percent bio-uptake
- Risks are additive

Table 4 3 qualitatively describes the general assumptions used in the risk assessment, and their effect on the risk assessment

4 9 2 Carcinogenic Risk Uncertainties

Numerous references (EPA, 1990b, ICRP, 1980) provide numerical estimates of the risk of fatal cancer induction from ionizing radiation These estimates may be a function of dose to an individual organ, whole body dose, duration of exposure, or quantity of radioactive material ingested or inhaled

A single slope factor (EPA, 1990b) was chosen to estimate lifetime risk of fatal cancer as a function of the receptor's lifetime intake of the individual radionuclide Greater accuracy resulting from the use of more situation-specific factors would make the magnitude of the other uncertainties in the estimation of human intake of radionuclides Based on a review of current risk estimates, it is assumed that the use of the single risk factor will generate an overestimation or underestimation of one order of magnitude compared to the use of a situation-specific factor

Because of the low probability of cancer induction at the levels of human exposure to radioactive material normally encountered in the environment, additional uncertainties arise from extrapolating risk estimates from much higher levels, where deleterious effects may be observed

TABLE 4.3

ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION SITES 200-202, ROCKY FLATS PLANT

Assumption	Effect on Risk		
	May Over-Estimate Risk	May Under-Estimate Risk	May Over/ Under-Estimate Risk
Environmental Sampling and Analysis			
Sufficient samples may not have been taken to characterize the matrices being evaluated			Moderate
Systematic or random errors in the radiochemical analyses may yield erroneous data			Low
Plutonium concentrations reported as "below method detection limit" are considered to be a non-detect data point		Low	
The qualitative public health evaluation is based on the chemical of concern (Pu) only This may represent a subset of the radionuclides possible at the site		Moderate	
Exposure Parameter Estimation			
The standard assumptions regarding body weight, period exposed, life expectancy, population characteristics, and lifestyle may not be representative for any actual exposure situation			Moderate
The amount of media intake is assumed to be constant and representative of the exposed population	Moderate		

TABLE 4.3

ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION SITES 200-202, ROCKY FLATS PLANT
(continued)

Assumption	Effect on Risk		
	May Over-Estimate Risk	May Under-Estimate Risk	May Over/ Under-Estimate Risk
Exposure to contaminants remains constant over exposure period	Moderate		
Concentration of contaminants remains constant over exposure period	High		
All plutonium is available for inhalation in respirable-size particles	High		
For most contaminants all intake is assumed to come from the medium being evaluated This does not take into account other contaminant sources such as diet, exposures occurring at locations other than the exposure point being evaluated, or other environmental media which may contribute to the intake of the chemical (i e , relative source contribution is not accounted for)		Moderate	
Environmental Parameter Measurement			
Food does not contribute to plutonium uptake		Moderate	
Dermal absorption of plutonium from soil is negligible		Low	

TABLE 4.3

ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION SITES 200-202, ROCKY FLATS PLANT
(continued)

	Effect on Risk		
	May Over-Estimate Risk	May Under-Estimate Risk	May Over/ Under-Estimate Risk
Toxicological Data			
Risks are assumed to be additive Risks may not be additive because of synergistic or antagonistic actions or other chemicals			Moderate
Assumes absorption is equivalent across species. This is implicit in the derivation of the acceptable intakes or cancer slope factors in this assessment.			Low
Extrapolation of toxicity data from species to species, and from laboratory animals to animals in the field			Moderate

Because of gaps in current scientific understanding of radiological carcinogenesis, radiological cancer risk assessment requires the use of a series of judgmental decisions on numerous unresolved scientific issues These judgmental decisions lead to uncertainties in cancer risk assessment because major assumptions are necessary for data extrapolation The four main data extrapolations are discussed in the following

- The extrapolation of experimental results across species from laboratory animals to humans
- The extrapolation of data from high-dose region of exposure of human or laboratory animals to the low-dose region of exposure of the general population
- The extrapolation of data across exposure durations from acute to chronic cases
- The extrapolation of data across age groups from adults to children or across ethnic populations

The uncertainties associated with these four basic data extrapolations are inherent in EPA slope factors for radionuclides and risk coefficients used in conventional radiological risk assessment methodology These uncertainties in risk estimation are discussed in the following paragraphs

4 9 2 1 Internal Exposure

Uncertainties in internal dose calculations based on ICRP models arise primarily from five sources. 1) the uncertainty in reference man data (age- and sex-specific differences and biological and ethnic variability in anatomical and physiological parameters), 2) the uncertainty in the lung and GI tract models describing the translocation and absorption of inhaled or ingested radionuclides into the blood (e g , the uncertainty in the anatomical model of the lung and GI tracts and age-specific physiological and morphological properties of the models), 3) the uncertainty associated with the formulation of the ICRP (1988a) biokinetic models describing the distribution and retention of radioactivity among the various organs in the body (e g , the biokinetic models are mainly based on animal data and often estimate excretion inaccurately, the growth of radioactive daughters is usually handled unrealistically), 4) the uncertainty in the dose models used to calculate the absorbed dose to organs from radionuclides retained in the body (nonuniform distribution of the activity is normally found in human organs), and 5) the uncertainty in the model parameters (e g , absorption fraction [f_1], which contribute the largest uncertainty in the GI tract model, intake rate, and effective half-life)

Uncertainties in risk estimation from internal exposure arise from the following sources 1) the assumption of the dose response model for estimating radiation-induced cancer risks at low doses and low dose rates based on data at high doses and high dose rates, 2) the choice of the risk models, latency period, and expression period for various types of radiation-induced cancers beyond the years of observation, 3) the age-specific parameters (risk coefficients) used for both absolute and relative risk models obtained from the Japanese atomic bomb survivor data, based on relative high doses and Japanese populations, 4) the use of age-specific mortality rates based on data collected in the United States in 1970, and 5) the use of mortality-to-incidence risk ratios for various types of cancers (Cancer incidence statistics are incomplete, and there is a possibility of differences in the relative frequency of cancer types between radiogenic cancers and those caused by other factors)

4 10 DATA NEEDS

It is evident that sufficient field data are lacking to perform an adequate quantitative risk assessment of Sites 200-202 The following quantitative information would greatly increase the accuracy of any future risk assessment Many of the parameters listed below have been quantified for the RFP as a whole, however, the applicability of the existing data to Sites 200-202 has not been rigorously evaluated, and much of the existing data have not been validated An early step in the data acquisition process, therefore, should be to evaluate the applicability of existing environmental data from the RFP to Sites 200-202 While the following sections describe some of the additional information which will be required to conduct a quantitative risk assessment, the Sites 200-202 RFI/RI work plan will address these data needs in greater detail

4 10.1 Physical Parameters of the Sites

Sediment parameters such as soil particle size, determination of soil particle size fraction with which plutonium is associated, organic content, and bulk density should be determined Meteorological parameters such as the frequency distribution of wind speed, direction and annual stability class should be collected Worst case soil (exposed sediment) and meteorological conditions (i e , those conditions at the site most conducive to plutonium transport) should be identified

4 10 2 Determination of Fugitive Dust Impact

More site specific information of the potential for wind erosion from exposed sediments needs to be collected and evaluated

4 10 3 Hydrology

The surface and ground water characteristics at Sites 200-202 need to be adequately characterized as they relate to contaminant transport Site specific data need to be collected as part of the RFI/RI activity Stratified water samples should be collected from the reservoirs.

4 10 4 Radiological Characterization

The lateral and vertical extent and magnitude of all plutonium and americium isotopes (and any other radiological parameters) in the reservoir sediments should be determined. The oxidation state and chemical state of plutonium and other radionuclides should be characterized. Sediment samples should be further characterized, and a standardized procedure should be made available for the quantitative risk assessment

4 10 5 Other Contaminants

Additional characterization of the site for potential inorganic and organic contaminants needs to be conducted The media of greatest concern are sediments, surface water, and ground water

4 10 6 Biota

Biota should be characterized. Analysis of both plutonium and americium uptake should be performed

5.0 CONCLUSIONS AND RECOMMENDATIONS

Over 30 documents detailing studies of Sites 200-202 were reviewed in preparing this report. These studies address different aspects of the Sites and have been conducted using markedly different techniques While this inconsistency in approach and technique has limited the usefulness of the existing data relative to IAG requirements, the following conclusions can be drawn from the body of available information for Sites 200-202

- Plutonium and americium (a decay product of plutonium) are the only known contaminants in the reservoirs attributable to RFP releases This conclusion is based on extensive water quality monitoring data for Great Western Reservoir and Standley Lake and analysis of bottom sediment samples for numerous potential RFP-derived contaminants, including various radionuclides and beryllium.

- Plutonium-bearing horizons of bottom sediments in Great Western Reservoir and Standley Lake have been covered by subsequent sedimentation The highest sediment plutonium concentrations were found to exist in the deepest areas of each reservoir The concentrations of plutonium in the sediments in areas of highest exposure potential (i e , near-shore areas) of Great Western Reservoir and Standley Lake are above background levels, as measured by several past studies in sediments of Colorado Front Range reservoirs believed to be unaffected by RFP releases

- Maximum plutonium concentrations measured to date in Great Western Reservoir sediments are several times higher than those measured to date in Standley Lake sediments

- Only four sediment samples have been collected (all in 1970) to assess plutonium concentrations in Mower Reservoir sediments The highest plutonium concentrations measured were roughly twice the estimated background concentration due to atmospheric testing fallout, and were several times lower than the highest concentrations measured to date in Standley Lake

- Plutonium is strongly adsorbed to the clay-rich sediments typical in impoundments near the RFP Studies have shown that plutonium in the reservoir sediment columns is effectively immobilized.

- Routine water quality monitoring indicates that water quality in Standley Lake and Great Western Reservoir has not been measurably impacted by plutonium in the reservoir sediments. A single water sample collected in 1970 from Mower Reservoir showed background plutonium concentrations (background is due to atmospheric testing fallout)

- Residential tap water derived from Standley Lake and Great Western Reservoir is routinely analyzed for plutonium Results consistently indicate that plutonium concentrations are well below CDH drinking water standards

- Of the many potential exposure pathways identified for the reservoirs, the airborne pathway from reentrainment of exposed sediments is considered the most significant pathway that can convey plutonium to human receptors from Sites 200-202. Airborne plutonium concentrations measured by air monitors downwind of Sites 200-202 have remained well below the 0 02 picocuries per cubic meter (pCi/m^3), or 0 0007 becquerel per cubic meter (Bq/m^3) standard set by DOE All potential exposure pathways, however, will be addressed under scheduled RCRA Facility Investigation/Remedial Investigation (RFI/RI) activities at Sites 200-202

While the available data for Sites 200-202 point to the above conclusions, they are not sufficient to support a quantitative risk assessment To confirm these conclusions with quantitative data, it is recommended that additional site data, including meteorological parameters and sediment and air samples be collected. Further sediment sampling should also be performed to confirm conclusions concerning plutonium concentrations and mobility in sediments at Sites 200-202 A quantitative risk assessment can then be performed to quantify the human health risks associated with the three reservoirs. These data collection activities should be integrated into scheduled RFI/RI activities

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1.0 INTRODUCTION

A baseline human health risk assessment has five basic components, these are

- Data collection and evaluation
- Exposure assessment
- Toxicity assessment
- Risk characterization
- Uncertainty analysis

Each of these facets of a risk assessment need to be performed in an appropriate manner so that a quantitative risk assessment is performed

This section examines the "Data Collection and Evaluation" that has been performed on Sites 200-202 with respect to EPA's Guidance for Data Useability in Risk Assessment (EPA 540/G-90/008), dated October 1990 The following criteria were used to evaluate and compare historical data

1 Was an adequate conceptual model of the site included?

2 Were data quality objectives stated?

3 Were key site characteristics documented?

4 Were all appropriate media sampled?

5 Were all key areas sampled?

6 Did sampling include media along potential routes of migration?

7 Were sampling locations consistent with the nature of contamination?

8 Were sampling efforts consistent with field screening and visual observations in locating hot spots?

9 Were detailed sampling maps provided, including the location, type and numerical code of each sample?

10 Did sampling include appropriate QA/QC measures?

11 Were background samples collected from appropriate areas?

12 Were any site-related chemicals eliminated from analysis without appropriate justification?

13 Were appropriate analytical methods employed for collection data?

14 Did the data meet the stated data quality objectives?

15 Were appropriate data qualifiers used for the analytical data?

The results of this evaluation are summarized in this appendix under Data Useability Worksheets In reviewing these worksheets it became clear that the available data would not support a quantitative risk assessment Therefore the risk assessment that was developed for Sites 200-202 was performed to determine if there was the presence/absence of an imminent hazard to the public A second goal was to identify data needs for a future work plan that would direct remedial investigation (RI) data collection

Some inherent uncertainty is associated with any numerical risk coefficient calculated in the development of a health risk assessment The historical data were not intended for use in a quantitative risk assessment and therefore meets few of the current standards for data useability as outlined in the EPA Guidance Document for Data Useability in Risk Assessment (1990) All the data reviewed attempt to characterize the location and magnitude of the soil concentration of 239 Pu (source term) at Site 199 The source term is the linchpin upon which any risk assessment is based, and if the data cannot adequately be defended as valid, a quantitative risk assessment that has any validity is impossible to perform None of the Sites 200-202 data reviewed meets the minimum criteria of data useability Instead, a preliminary qualitative risk assessment has been developed that evaluates the relative magnitude of the source term, and whether human receptors are currently experiencing any imminent hazard from this source term

The following documents are listed in Appendix D, but they were not reviewed against all of the criteria found in the data useability guidance document due to the lack of information contained within them

- National Dam Safety Program Standley Lake Dam
- Plutonium Chemistry

- Great Western Reservoir Pre-Feasibility Study for Surface Water Interceptor System
- A Survey of Plutonium Contamination Released to the Sanitary Sewer System
- The Study of Plutonium in Aquatic Systems of the Rocky Flats Environs
- General Sediment Sampling Program Proposed Off-Site Sampling Activities
- Standley Lake Sediment Sample Collection Summary, August 1984
- Geology of Standley Lake Area, July 1982
- Battelle PNL Report Radionuclide Concentration in Reservoirs, Streams, and Domestic Waters, February 1980
- Battelle PNL Report, "Radionuclide Concentration in Reservoirs, Streams, and Domestic Waters Near the Rocky Flats Installation"
- Geology of Standley Lake Area, Jefferson County, Colorado
- Standley Lake Sample Collection Summary, August 1984
- Time Pattern of Off-Site Plutonium Contamination from Rocky Flats Plant by Lake Sediment Analysis, E Hardy
- Radioactivity Levels in the Divions of the RFP, Part II, December 15, 1973
- Munincipal Sampling, Water Quality Control Board
- Research Proposal for Radionuclide Limnochronology and Background Levels of Plutonium in Front Range Lakes
- Investigative Report of the 1973 Tritium Release at the RFP in Golden, July, 1974
- Plutonium in the Aquatic Environment Around the Rocky Flats Facility, 1971

The following approach to the data useability evaluation for Sites 200-202 is taken from the EPA Guidance Document for Data Useability in Risk Assessment, EPA 540/G-90/008, October 1990 (EPA, 1990a)

2.0 REPORT TO RISK ASSESSOR

As stated in the EPA Guidance for Data Useability in Risk Assessment, the minimum data, documentation and report materials needed to prepare a risk assessment are:

- A description of the site, including a detailed map showing the location of each sample, the site location relative to surrounding structures, terrain features, receptor populations, indications of air and water flow, and a description of the operative industrial process (if any)
- A description and rationale of the sample design and sampling procedures
- A description of the analytical methods used
- Results for each analyte and each sample, qualified with respect to analytical limitations
- Sample-specific quantitation limits (SQLs) and detection limits for undetected analytes, with an explanation of the detection limits reported and detection limit qualification for analytical limitations
- A narrative explanation of the level of data review used and the resulting data qualifiers indicating direction of bias, based on the assessment of the results from quality control samples (i e , blanks, duplicates, and field and laboratory spikes
- A description of field conditions and physical parameter data as appropriate for the media involved in the exposure assessment

As stated in the guidance document, if any of this information is not available and cannot be obtained, it may not be possible to perform a quantitative baseline risk assessment

3.0 ASSESSMENT OF DOCUMENTATION

According to the guidance document three types of documentation must be assessed Chain-of-Custody records, Standard Operating Procedures, and field and analytical records

Chain-of-custody records must document the sample locations and the date of sampling so that sample results can be related to geographic location and to specific sample containers If a sample result cannot be related to a sampling date and the point of sample collection, the results are unusable for a quantitative risk assessment Full scale chain-of-custody procedures (extending from sample collection through analysis) are not required for risk assessments, although they are required for other purposes, such as enforcement or cost recovery

In all cases, the reports reviewed had no chain-of-custody records. Sample location records were poor, and sampling dates were not included As stated above, if sampling results cannot be related to a sampling date and the point of sample collection, the results are unusable for a quantitative risk assessment

No field or analytical records were included with the documents reviewed, nor were SOPs available to allow comparison of the field and analytical records for each report. Since SOPs were not included, it is impossible to determine the level of systematic and random error associated with sampling and analysis within any of the reports reviewed.

4.0 ASSESSMENT OF DATA SOURCES

Minimum analytical data requirements for a risk assessment as stated in the guidance document stipulate that one sample per medium exposure pathway be analyzed using a broad spectrum analytical technique, such as GC-MS methods for organic analytes, or ICP for inorganic analytes The lack of a broad spectrum analysis for any samples at Sites 200-202 from a fixed laboratory source results in an increased probability of false negatives because all chemicals of potential concern at the site may not be identified In the absence of a broad spectrum analysis, the best corrective action is to collect additional samples Since additional samples have not been obtained from Sites 200-202, the probability of false negatives and positives should be considered high Therefore the level of certainty in performing a quantitative risk assessment is greatly decreased

Field measurements of physical characteristics of the site, medium, or contamination source are critical data, whose omission can significantly affect the validity of a quantitative risk assessment. Physical site information is required to perform exposure fate and transport modeling Examples of such data are particle size, pH, clay content and porosity of soils, wind direction and speed, topography and percent vegetation The EPA Risk Assessment Guidance (RAGS) describes minimum field measurements to be collected for site characterization RAGS Exhibit 4-2, "Examples of Modeling Parameters for Which Information May Need to be Obtained During a Site Sampling Investigation," provides a list of data elements according to medium modeling category If not collected during sampling, these parameters cannot be determined The use of default options and routines to estimate missing values allows the use of the model but increases the uncertainty associated with the exposure assessments

Although large amounts of this data exist for the RFP, none of the above parameters have been characterized for Sites 200-202 The lack of field measurements directly applicable to Sites 200-202 greatly reduces the level of certainty in the performance of a quantitative risk assessment. Therefore general statements concerning physical site information were utilized for the qualitative risk assessment

5.0 ANALYTICAL METHOD

A critical facet of data useability as described in the guidance document requires that the analytical methods used to measure plutonium contamination in sediment have sufficient quality control measures built into the sample collection and analysis The preparation of samples prior to counting is an important consideration, which is a multi-step process that achieves the following objectives (1) the destruction of the sample matrix to reduce alpha-and beta particle absorption, (2) the separation and concentration of radionuclides of interest to increase resolution and sensitivity, and (3) the preparation of the sample in a suitable form for counting Appropriate radioactive tracers must be selected and added to both the field and laboratory samples before a radiochemical procedure is initiated Of the documents reviewed, only the Illsley 1987 report partially describes the above methods used for radiochemical analysis Most of the documents reviewed do not state whether analysis was performed by a laboratory participating in the EPA Environmental Radioactive Intercomparison Program, which provides quality assurance oversight for radiation measurement laboratories

6.0 DATA REVIEW

The EPA Data Useability Guidance Document lists two criteria for data review, that of timeliness, and the level and depth of review The first criteria is of little importance for this project, but the second criteria is a critical factor that the data must meet for it to be used in the risk assessment A statement concerning the data review process is absent from all documents that were used to develop the qualitative risk assessment The timeliness, level, and depth of review is unknown It can be assumed that all documents went through a normal quality assurance review, but even this is not stated. It is unclear if computer algorithm programs were validated, or if data entry was checked Therefore based on the data review process criterion, all documents would be rejected

7.0 ASSESSMENT OF SAMPLING DATA QUALITY INDICATORS

As stated in the Guidance Document, five basic data quality indicators must be assessed prior to utilizing data in a quantitative risk assessment

1 Completeness

Completeness is a measure of the amount of useable data resulting from data collection activities A description of the number of samples required to adequately characterize each media should be included that at a minimum references Standard Operating Procedures (SOPs) and the Sampling and Analysis Plan (SAP)

The Illsley document uses the methodology of collecting a large number of sample locations per sector and compositing these into one sample per sector Although this is an accepted methodology for soil sample collection over large areas, not enough documentation was made available to determine if a sufficient number of samples were collected to adequately characterize the site

2 Comparability

Comparability expresses the confidence with which data are considered to be equivalent Analytical methods and sampling protocol must be stated in each report to allow comparison of each of the data sets, since field and laboratory variability may significantly affect the results

None of the reports reviewed are judged to be adequate based on an examination of comparability, since sample design and analytical methods vary greatly between reports

3 Representativeness

Representativeness expresses the extent to which data define the risk to human health and the environment Samples must be collected in a way that generates data which reflects the site characteristics, and must be analyzed in a way which represents the properties of the field sample Lack of representativeness in the media sampled may result in the detection of false negatives and may cause the omission of potential exposure pathways in the risk assessment

Although sample preparation procedures were similar for some of the reports, it is still unclear whether the process of compositing subsamples in each sector produces a sample data set representative of the exposure area in question Information concerning higher concentrations and hot spots is lost when analyzing soil composites

4 Precision

Precision is a measure of the variability of a set of measurements compared to the mean and is usually reported as a coefficient of variation or a standard deviation of the arithmetic mean

Here again, it is impossible to compare the data sets of the reports available for Sites 200-202 because of the large variability in precision of the analytical results The two basic activities performed in the assessment of precision are estimating sample variability from the observed spatial variation and estimating the measurement error attributed to the data collection process

Neither one of these can be accomplished for Sites 200-202, given the information presented in the reports and leads to an unacceptable level of uncertainty. Therefore, the estimation of the average concentration of Pu may not be representative of the site

5 Accuracy

Accuracy is controlled primarily by the analytical process and is reported as bias The sample design plan and sample collection plan relates directly to this bias, and since neither of these documents were included for review, it is impossible to determine the accuracy of the reports The estimate of accuracy is further compromised by the exclusion of data relating to field and laboratory spike results Since an estimation of the accuracy of the data cannot be performed, the data should not be included for use in a quantitative risk assessment

8.0 APPLICATION OF DATA TO RISK ASSESSMENT

The Data Useability worksheets provided in Appendix A provide a detailed examination of the data quality across the various assessment phases To summarize the data and determine useability the following four questions are applied to each data report, incorporating the data useability criterion evaluated in the worksheets These questions are taken directly from Chapter 6 of the EPA Guidance Document for Data Useability

CRITERION	SUMMARY
1 What contamination is present and at what levels?	Analytical methods, data review, analytical precision and accuracy combine to allow for a probability of false negatives Criterion not met
2 Are site concentrations sufficiently different from background?	Although background measurements were not collected, the levels of Pu present are greater than what can be attributed to world-wide fallout. Therefore it is assumed that the plutonium measured at Sites 200-202 originated from the RFP Criterion met.
3 Are all exposure pathways identified and examined?	The nature of the pathways to be examined is critical to the characterization of risk at the site None of the documents reviewed provide identification of exposure pathways Criterion not met.
4 Are exposure pathways fully characterized?	To be fully characterized, the exposure pathway must have been appropriately sampled Data Quality Indicators such as completeness, comparability, representativeness, precision, and accuracy all must be within acceptable limits for the exposure pathways to be accurately characterized The information listed above is lacking in all of the documentation provided Criterion not met.

Since none of the documents meets the basic criterion of data useability a quantitative risk assessment based on such data would not yield useful results and would not be defensible

9.0 SUMMARY

An examination of the data available for Sites 200-202 indicates that few of the criteria found in the EPA Guidance Document for Data Useability are met The data collected were of limited quality and specificity, a sampling design program was not initiated to collect representative samples from all media and exposure pathways, and no meaningful statistical analysis were conducted on the data set prior to publication of the reports, including Data Quality Indicators and sample specific quantitation limits (SQLs)

Therefore, based on the guidance found in the Data Useability for Risk Assessment only qualitative statements concerning risk are possible These statements are based on historical information and the general behavior and transport of plutonium in the environment No numerical measures can be derived to indicate the potential for adverse effects, and the level of certainty cannot be assessed The risk to human health may thus be considered only in qualitative terms, which by the reference document is an acceptable method when data do not support a more rigorous quantitative analysis

TABLE A1.1

DATA SOURCES
OPERABLE UNIT NO. 3, Sites 200-202, ROCKY FLATS PLANT

Data Source	Nature of Data
United States Atomic Energy Commission, "Plutonium in Soil Around the Rocky Flats Plant," by P W Krey and E P Hardy, Health and Safety Laboratory USAEC, New York, NY, HASL-235, 1 August 1970	Plutonium concentrations in soil samples collected in early 1970 from 33 sits extending as far as 40 miles from Rocky Flats Plant, including sites within and around Sites 200-202
Dow Chemical USA, "Soil Sampling East of Indiana Avenue," by R W Loser and R L Tibbals, Product and Health Physics Research Service Report No 317-72-186, 29 November 1972	Plutonium concentrations in soil samples collected on November 17, 1972 from 20 sites within and around Sites 200-202
Rockwell International, "Results of Special Soil Samples Collected Adjacent to the Rocky Flats Plant Site," by C T Illsley, Environmental Analysis and Control, ES-376-77-201, 7 September 1977 (revised 30 November 1979)	Selected radionuclide concentrations (including plutonium) in soil samples collected in August, 1976 from 25 sites within and around Sites 200-202
Colorado Department of Health, "Radioactive Soil Contamination (Cesium-137 and Plutonium) in the Environment Near the Rocky Flats Nuclear Weapons Plant," September 1977	Plutonium and cesium-137 concentrations in soil samples collected in 1977 from sites within and around Sites 200-202
Rockwell International, "Plutonium Concentrations in Soil on Lands Adjacent to the Rocky Flats Plant," by C T Illsley and M W Hume, Energy Systems Group, LPR-1, 16 March 1979	Plutonium concentrations in soil samples collected in 1976 and 1977 from sites within and around Sites 200-202
Rockwell International, "Disclosure to the City of Broomfield," 22 January 1985	Page 9 Average plutonium concentrations in soils on City of Broomfield acreage at Sites 200-202 Page 15A Average annual plutonium concentrations in air and soil within and around Sites 200-202
Rockwell International, "Soil Sample Collection and Analysis for Plutonium on Lands Adjacent to Great Western Reservoir for the City of Broomfield," by C T Illsley, EAC-47-85-1, 10 April 1985	Plutonium concentrations in 15 composite soil samples collected in 1985 from 10-acre plots within the City of Broomfield acreage at Sites 200-202
Rockwell International, "Remedial Action Program on Jefferson County Open Space Land in Section 7, T2S, R69W, South of Great Western Reservoir," by C T Illsley, EAC-420-87-1, 15 January 1987	Plutonium concentrations in composite soil samples collected in 1977 and 1985 from 10-acre plots within Sites 200-202
"Rocky Flats Plant Site Environmental Report," (published annually since 1971 by EG&G Rocky Flats, Inc and their predecessors, known prior to 1988 as "Annual Environmental Monitoring Report")	Summaries of all environmental investigations and monitoring conducted on and around the RFP during the current year (summarizes data included in monthly environmental monitoring reports)

TABLE A1.2

PLUTONIUM IN SOIL AROUND THE ROCKY FLATS PLANT, APRIL 1, 1970

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report only includes limited sampling data locations for Sites 200-202 Majority of report applies to areas outside of Sites 200 202 No data sets included, only data summary No interpretation of data useability No narrative describing specific sampling of analytical problems Results are qualified for analytical limitations Partial interpretation of QC data included. Soil sampling technique different than for other documents Document not generated for use in risk assessment.	Reject	
2.	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or quality assurance project plan provided Inadequate site description, no detailed map provided with sample locations	Reject	
	B SOPs	The data tables provided compare the results of different methods of soil collection. This supports the contention that a variation in sample collection procedures can have a significant effect on analytical results A description of sampling design is provided	Reject	
	C Field and Analytical Records	No field logs or raw data available No chain of custody records Selection and identification of sampling points not documented No documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Analytical results listed in Table A vary between laboratories Analytical results are listed by depth of sample	Qualified Accept	
	B Non analytical	Use CDH 1977 No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography, respirable Fraction of PU, depth of contamination in soil, etc	Reject	
4	Analytical Methods	Analytical methods not stated. Quality control measures mentioned but not described Replicate analysis performed but result not stated. Method detection limits percent recovery, LLD and MDA stated Laboratory performing analysis identified	Qualified Accept	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level and depth of review not stated in document. Level of quality assurance/quality control review unknown	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data sets Assumption is that 100% of samples collected were correctly analyzed. No explanation why many more sampling points identified on map without corresponding analytical value No data qualifiers presented with data Only PU and CS analyzed	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	This report points out the variability introduced in the analytical results due to change in sample collection procedures It is not possible to compare the results in this report with other reports Sampling not performed based on temporal or spatial variation In addition, analysis from different laboratories resulted in variation of the PU concentrations	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data cannot be used for a quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations of the site. Only one exposure pathway was sampled (soil) No air or water data is available directly related to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	Table 8, duplicate soil sampling results given as mCi/km^2 Field blanks, trip blanks and internal standards collected. Counting error stated. No field blanks, trip blanks, internal standards, or standard soil analysis was performed Replicate analysis was performed but the results were not listed in the report Soil concentrations reported as averages rather than included as a complete data set. Counting error not stated.	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	E Accuracy	Percent recovery analysis performed Description of minimum QA/QC data included No documented QA review	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.3

COMMITTEE EVALUATION OF PLUTONIUM LEVELS WITHIN AND SURROUNDING RFP, JULY 9, 1971

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report only includes limited sampling data locations for Sites 200-202 Majority of report applies to areas outside of Sites 200 202 No data sets included only data summary No interpretation of data useability No narrative describing specific sampling or analytical problems Results are qualified for analytical limitations Interpretation of QC data included Soil sampling technique different than for other documents Document not generated for use in risk assessment.	Qualified Accept	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or quality assurance project plan provided Inadequate site description, no detailed map provided with sample locations	Qualified Accept	
	B SOPs	The data tables provided compare the results of different methods of soil collection. This supports the contention that a variation in sample collection procedures can have a significant effect on analytical results A description of sampling design is provided.	Reject	
	C Field and Analytical Records	No field logs or raw data available No chain of custody records Selection and identification of sampling points not documented No documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Analytical results listed vary between laboratories with no accompanying explanation	Qualified Accept	
	B Non-analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography, respirable Fraction of PU, depth of contamination in soil, etc	Reject	
4	Analytical Methods	Analytical methods stated Quality control measures described. Replicate analysis performed and results stated Method detection limits percent recovery, LLD and MDA stated Laboratory performing analysis identified.	Accept	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level and depth of review not stated in document. Level of quality assurance/quality control review unknown	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data sets Assumption is that 100% of samples collected were correctly analyzed. No explanation why many more sampling points identified on map without corresponding analytical value No data qualifiers presented with data Only PU analyzed	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	This report points out the variability introduced in the analytical results due to difference in sample collection procedures It is not possible to compare the results in this report with other reports Sampling not performed based on temporal or spatial variation In addition, analysis from different laboratories resulted in variation of the PU concentrations	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data cannot be used for a quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations of the site. Only one exposure pathway was sampled (soil) No air or water data is available directly related to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	Results given as mCi/km^2 Field blanks, trip blanks and internal standards collected. Counting error stated No field blanks, trip blanks, internal standards, or standard soil analysis was performed. Replicate analysis was performed but the results were not listed in the report. Soil concentrations reported as averages rather than included as a complete data set. Counting error not stated.	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	E Accuracy	Percent recovery analysis performed Description of minimum QA/QC data included No documented QA review	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.4

SOIL SAMPLING EAST OF INDIANA AVENUE, NOVEMBER, 1972

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report includes only limited sample locations for Sites 200-202. Majority of report applies to areas outside of Sites 200-202. No data set included, only data summary No interpretation of data useability No narrative summary describing specific sampling or analytical problems Results not qualified for analytical limits Interpretation of QC data not included Document not generated for use in risk assessment.	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or Quality Assurance Project Plan provided Inadequate site description No detailed map provided for sampling locations from Table I. No map provided for sampling locations from Table II.	Reject	
	B SOPs	No description of sampling design Procedures omitted.	Reject	
	C Field and Analytical Records	No field logs or raw data available Selection and identification of sampling points not documented	Reject	
3	Data Sources A Analytical	Analytical data reported as mCi/km^2 rather than as pCi/g, and is totally unusable for a risk assessment. No data available for samples listed in Table II Samples analyzed for PU only	Reject	
	B Non analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography	Reject	
4	Analytical Methods	Analytical methods and procedures not referenced Quality control measurements no described. Replicate Analysis not performed, Method detection limits percent recovery, LLD, and MDA not stated Laboratory performing analysis not stated	Reject	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No data results for sampling locations in Table II. No indications if data collection and analysis problems affected the completeness of data set. No data qualifiers presented with data	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	Data reported in mCi/km^2 and is not comparable with other reports This report points out the variability introduced in the analytical results due to change in sample collection procedures It is not possible to compare the results in this report with other reports Sampling not performed based on temporal or spatial variation.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	Data reported in mCi/km2 and is not comparable with other reports The data cannot be used for a quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations of the site. Only one exposure pathway was sampled (soil) No air or water data is available directly related to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	Data reported in mCi/km2 and is not comparable with other reports No field blanks, trip blanks, internal standards, or standard soil analysis was performed. Replicate analysis was performed but the results were not listed in the report. Soil concentrations reported as averages rather than included as a complete data set. Counting error not stated.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Data reported in mCi/km2 and is not comparable with other reports Percent recovery analysis not performed Description of minimum QA/QC data not included No documented QA review	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.5

RADIO ACTIVE SOIL CONTAMINATION IN THE ENVIRONMENT NEAR THE ROCKY FLATS NUCLEAR WEAPONS PLANT, CDH 1977

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report only includes limited sample locations for Sites 200-202. Majority of report applies to areas outside of Sites 200-202 No data set included, only data summary No interpretation of data useability No narrative summary describing specific sampling of analytical problems Results not qualified for analytical limitations Interpretation of QC costs not included Document not generated for use in risk assessment	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling end analysis plan or Quality Assurance project plan provided Inadequate site description, no detailed map provided with sample locations Many sample points are shown on map in Figure 5 but have no corresponding analytical value	Reject	
	B SOPs	The data tables provided compare the results of different methods of soil collection. This supports the contention that a variation in sample collection procedures can have a significant effect on analytical results A description of sampling design is provided	Accept	
	C Field and Analytical Records	No field logs or raw data available No chain of custody records Selection and identification of sampling points not documented No documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Analytical data results reported as averages rather than including hot spot values Samples analyzed for 239 PU and 147 Cs only No chemical analysis performed? Solubility class for a PU not determined.	Reject	
	B Non analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography, respirable Fraction of PU, depth of contamination in soil, etc	Reject	
4	Analytical Methods	Analytical methods listed. Quality control measures mentioned but no described Replicate analysis performed but no data stated. Method detection limits percent recovery, LLD, MDA not stated. Unknown if laboratory performing analysis participating in Intercomparison program	Reject	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level and depth of review not stated in document. Level of quality assurance/quality control review unknown	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data sets Assumption is that 100% of samples collected were correctly analyzed. No explanation why many more sampling points identified on map without corresponding analytical value No data qualifiers presented with data Only PU and CS analyzed	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	This report points out the variability introduced in the analytical results due to change in sample collection procedures It is not possible to compare the results in this report with other reports Sampling not performed based on temporal or spatial variation	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data cannot be used for a quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations of the site. Only one exposure pathway was sampled (soil) No air or water data is available directly related to the site.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	No field blanks, trip blanks, internal standards, or standard soil analysis was performed Replicate analysis was performed but the results were not listed in the report. Soil concentrations reported as averages rather than included as a complete data set. Counting error not stated.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Percent recovery analysis not performed Description of minimum QA/QC data not included No documented QA review	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.6

RESULTS OF ANALYSIS FOR SPECIAL SOIL SAMPLES COLLECTED ADJACENT TO THE ROCKY FLATS PLANT SITE, SEPTEMBER, 1977

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report may include sample locations outside of Sites 200-202. No map included to locate sample points No data set included, only data summary No interpretation of data useability No narrative summary describing specific sampling or analytical problems Results not qualified for analytical limits Interpretation of QC data not included Document not generated for use in risk assessment.	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan sampling and analysis plan or Quality Assurance project plan provided No site description. No detailed sampling map provided	Reject	
	B SOPs	No description of sampling design, no procedures included.	Reject	
	C. Field and Analytical Records	No field logs or raw instrument data available No chain of custody records Selection and identification of sampling points not documented. No documentation concerning deviation from sampling plan or standard operating procedures	Reject	
3	Data Sources A Analytical	No raw analytical data provided only data summaries No high or hot spot data provided only averages Data reported as disintegrations per minute per gram of soil. Samples not analyzed for 241 Am	Reject	
	B Non analytical	No field measurement date available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography	Reject	
4	Analytical Methods	Analytical methods and procedures not adequately described. Method detection limits sample quantitation limits percent recovery not stated in report laboratory identified that performed analysis Table II Comparative Analysis indicates an unacceptable variation for analysis of certain radionuclides	Reject	
5	Data Review	Data review prior to publication of document is unknown The timeliness, level, and depth of review not stated in document	Reject	
6	Data Quality Indicators A Completeness	Based on the data presented it is not possible to compare or equivocate the results in this report with other reports Sampling not performed based on special or temporal variation.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	The data collected cannot be used for quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations at the site Only one exposure pathway was sampled (soil) no air data is available directly relating to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	Field blanks, duplicates, and standard soil analysis were performed but the results were reported as a summary rather than a complete data set.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	Field blanks, duplicates, replicates and standard soil analysis were not collected No complete data sets, only data summary Counting error not stated.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Isotopic tracer was added to determine percent recovery, but not during sample collection phase The report states a plutonium tracer was 236 PU was added to the soil samples after compositing to determine percent recovery However, no tracer was added to the field samples to assure 100% recovery during the soil collection and compositing process	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.7

PLUTONIUM CONCENTRATIONS IN SOIL ON LANDS ADJACENT TO THE ROCKY FLATS SITE, MARCH 1979

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	No data set included, only data summary No interpretation of data useability, no narrative summary describing specific sampling or analytical problems results not qualified for analytical limitations Interpretation of QC data is included. Document not generated for use in risk assessment	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or Quality Assurance project plan provided Inadequate site description, no detailed map w/sample locations	Reject	
	B SOPs	No detailed description of sampling design Procedures omitted, vegetative cover may have been removed prior to soil sampling, thus biasing the sample Samples collect on random basis, rather than by using a low energy gamma detector such as a FIDLER to locate potential sample points	Reject	
	C Field and Analytical Records	Report states that sample collection logbook used. No field logs or raw instrument data available No chain of custody records, selection and identification of sampling points not document, no documentation concerning deviation from sampling and analysis plan or standard operating procedures	Qualified Accept	
3	Data Sources A Analytical	Analytical data results for composite soil samples only no high or hot spot data, samples analyzed for 239 PU only, no chemical analysis performed and solubility class for 239 PU not determined	Reject	
	B Non-analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography	Reject	
4	Analytical Methods	Analytical methods and procedures and quality control measures listed Method detection limits, sample specific quantitation limits percent recovery not stated in report. Laboratory performing analysis certified by EMSL LV (EPA Environmental Radioactivity Intercomparison Program	Qualified Accept	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level, and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data set. Assumption is the 100% of samples collected were correctly analyzed. No data qualifiers presented with data	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	Based on the data presented it is not possible to compare or equivocate the results in this report with other reports Sampling not performed based on special or temporal variation.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data collected cannot be used for quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations at the site Only one exposure pathway was sampled (soil) no air data is available directly relating to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	Field blanks, duplicates, and standard soil analysis were performed but the results were reported as a summary rather than a complete data set.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	The report states a plutonium tracer was 236 PU was added to the soil samples after compositing to determine percent recovery However, no tracer was added to the field samples to assure 100% recovery during the soil collection and compositing process	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.8

DISCLOSURE TO THE CITY OF BROOMFIELD, JANUARY 22, 1985

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	No data set included, only data summary No interpretation of data useability, no narrative summary describing specific sampling or analytical problems results not qualified for analytical limitations Interpretation of QC data is included. Document not generated for use in risk assessment. A table is included that relates soil concentrations and airborne concentrations of Pu at Sites 200-202, but is not qualified with the needed information for data useability	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or Quality Assurance project plan provided Inadequate site description, no detailed map w/sample locations	Reject	
	B SOPs	No detailed description of sampling design Procedures omitted, vegetative cover may have been removed prior to soil sampling, thus biasing the sample Samples collect on random basis, rather than by using a low energy gamma detector such as a FIDLER to locate potential sample points	Reject	
	C Field and Analytical Records	No field logs or raw instrument data available No chain of custody records, selection and identification of sampling points not document, no documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Analytical data sources reported as summary rather than as data sets	Reject	
	B Non-analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil wind direction, topography	Reject	
4	Analytical Methods	Analytical methods and procedures and quality control measures not listed.	Reject	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level, and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data set. Assumption is the 100% of samples collected were correctly analyzed. No data qualifiers presented with data.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	Based on the data presented it is not possible to compare or equivocate the results in this report with other reports Sampling not performed based on special or temporal variation.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data collected cannot be used for quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations at the site Only one exposure pathway was sampled (soil) no air data is available directly relating to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	No indication of the number of field blanks, duplicates and standard soil analysis, or if they were even collected Results reported as summary rather than complete data set.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Data summary does not include information concerning percent recovery both for the field and analytical samples	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.9

SOIL SAMPLING COLLECTION AND ANALYSIS FOR PLUTONIUM ON LANDS ADJACENT TO GREAT WESTERN RESERVOIR FOR THE CITY OF BROOMFIELD APRIL 10, 1985

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report includes partial sample locations for Sites 200 202 No data set included, only data summary No interpretation of data useability No narrative summary describing specific sampling or analytical problems Results not qualified for analytical limitations interpretation of QC data not included Document not generated for use in risk assessment.	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis or Quality Assurance project plan provided Quality control statements duplicated in Illsley 1987 document Inadequate site description, no detailed map provided with sample locations	Reject	
	B SOPs	No detailed description of sampling design Procedures omitted, vegetative cover may have been removed prior to soil sampling thus biasing the sample. Samples collected on a random basis, rather than by using a low energy gamma detector such as a FIDLER to locate potential sample points	Reject	
	C Field and Analytical Records	No field logs or raw data available No chain of custody records Selection and identification of sampling points not documented No documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Analytical data results reported as averages rather than including hot spot values Composite soil samples taken, samples analyzed for 239 PU only No chemical analysis performed. Solubility class for 239 PU not determined.	Qualified Accept	
	B Non-analytical	No field measurement data available for site such as particle size, pH, clay content porosity of soil, wind direction, topography, respirable fraction of PU, depth of contamination in soil.	Reject	
4	Analytical Methods	Analytical methods and procedures referenced Quality control measures stated but not described Method detection limits, sample specific quantitation limits are percent recovery not stated in report. Laboratory performing analysis certified by EMSL-LV (EPA Environmental Radioactivity Intercomparison Program	Qualified Accept	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level and depth of review not stated in document. Level of quality assurance/quality control review unknown	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data sets Assumption is that 100% of samples collected were correctly analyzed. No data qualifiers presented with data. Only PU analyzed	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	Based on the data presented it is not possible to compare or equivocate the results in this report with other reports Sampling not performed based on special or temporal variation.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data cannot be used for a comprehensive quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations at the site Only one exposure pathway was sampled (soil) No air or water data is available directly related to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	Field blanks, duplicates, and standard soil analysis were performed but the results were reported as a summary rather than a complete data set.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	The report states a plutonium tracer was 236 PU was added to the soil samples after compositing to determine percent recovery However, no tracer was added to the field samples to assure 100% recovery during the soil collection and compositing process	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.10

REMEDIAL ACTION PROGRAM ON JEFFERSON COUNTY OPEN SPACE LAND IN SECTION 7, T2S, R69W SOUTH OF GREAT WESTERN RESERVOIR JAN. 15, 1987

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	No data set included, only data summary No interpretation of data useability, no narrative summary describing specific sampling or analytical problems results not qualified for analytical limitations Interpretation of QC data is included. Document not generated for use in risk assessment	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or Quality Assurance project plan provided Inadequate site description, no detailed map w/sample locations	Reject	
	B SOPs	No detailed description of sampling design Procedures omitted, vegetative cover may have been removed prior to soil sampling, thus biasing the sample. Samples collect on random basis, rather than by using a low energy gamma detector such as a FIDLER to locate potential sample points	Reject	
	C Field and Analytical Records	No field logs or raw instrument data available No chain of custody records, selection and identification of sampling points not document, no documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Analytical data results for composite soil samples only no high or hot spot data, samples analyzed for 239 PU only, no chemical analysis performed and solubility class for 239 PU not determined	Qualified Accept	
	B Non analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography	Reject	
4	Analytical Methods	Analytical methods and procedures and quality control measures listed Method detection limits, sample specific quantitation limits percent recovery not stated in report. Laboratory performing analysis certified by EMSL-LV (EPA Environmental Radioactivity Intercomparison Program	Qualified Accept	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level, and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data set. Assumption is the 100% of samples collected were correctly analyzed. No data qualifiers presented with data	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	Based on the data presented it is not possible to compare or equivocate the results in this report with other reports Sampling not performed based on special or temporal variation.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data collected cannot be used for quantitative risk assessment because only soil media was sampled, and collected in a manner that may not represent the true PU concentrations at the site Only one exposure pathway was sampled (soil) no air data is available directly relating to the site.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	Field blanks, duplicates, and standard soil analysis were performed but the results were reported as a summary rather than a complete data set.	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	E Accuracy	The report states a plutonium tracer was 236 PU was added to the soil samples after compositing to determine percent recovery However, no tracer was added to the field samples to assure 100% recovery during the soil collection and compositing process	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.11

SPECIAL REPORT 1989 CDH SURFACE SOIL SURVEY RESULTS

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	No data set included, only data summary No interpretation of data useability, no narrative summary describing specific sampling or analytical problems results not qualified for analytical limitations Interpretation of QC data is included. Document not generated for use in risk assessment	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or Quality Assurance project plan provided Inadequate site description, no detailed map w/sample locations	Reject	
	B SOPs	No detailed description of sampling design Procedures omitted, vegetative cover may have been removed prior to soil sampling, thus biasing the sample Samples collect on random basis, rather than by using a low energy gamma detector such as a FIDLER to locate potential sample points	Reject	
	C Field and Analytical Records	No field logs or raw instrument data available No chain of custody records, selection and identification of sampling points not document, no documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	No indication as to the analysis performed	Reject	
	B Non analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction topography	Reject	
4	Analytical Methods	No analytical methods listed Laboratory performing analysis not stated	Reject	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level, and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data set. Assumption is the 100% of samples collected were correctly analyzed. No data qualifiers presented with data	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	Based on the data presented it is not possible to compare or equivocate the results in this report with other reports Sampling not performed based on special or temporal variation Some data reported as dpm/g other data reported as parts per trillion	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data collected cannot be used for quantitative risk assessment because only soil media was sampled and collected in a manner that may not represent the true PU concentrations at the site Only one exposure pathway was sampled (soil) no air data is available directly relating to the site	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	D Precision	No indication of the number of field blank duplicates and standard soil analysis or if they were even collected Results reported as summary rather than completed data set.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Data summary does not include information concerning percent recovery both for the field and analytical samples	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.12

STANDLEY LAKE FISH TOXICS MONITORING REPORT, JANUARY 1990

Data Useability Criteria		Comments	Decision[1]
1	Reports to Risk Assessor	Calculations of risk from biotic uptake included Sufficient fish sampling performed at Standley Lake to characterize this pathway Sampling limited to Standley Lake, so results do not apply to Great Western Reservoir or Mower Reservoir Results qualified for analytical limits Document generated for use in risk assessment.	Accept for Standley Reject for Mower Reject for Great Western
2	Documentation A WP/SAP/QAPjP	EPA sample collection methodology referenced No bibliography provided No work plan sampling and analysis plan, or quality assurance project plan provided Inadequate site description, but map provided with general site sampling locations CDH Analytical Sample Methodology for reference	Qualified Accept for Standley Reject for Mower Reject for Great Western
	B SOPs	Some description of sample collection and handling Procedures referenced	Qualified Accept for Standley Reject for Mower Reject for Great Western
	C Field and Analytical Records	No field logs or raw data available Identification of sampling locations included.	Accept for Standley Reject for Mower Reject for Great Western
3	Data Sources A Analytical	Pu-239, Pu 240, and 21 other gamma-emitting fission products analyzed Am 241 not analyzed. Pesticides and heavy metals analyzed.	Qualified Accept for Standley Reject for Mower Reject for Great Western
	B Non-analytical	No discussion of why specific species of fish collected No discussion of potential mechanism of bioaccumulation	Reject Standley Reject Mower Reject Great Western
4	Analytical Methods	Analytical methods and procedures referenced Duplicate analysis performed on channel catfish composite for quality control Quality control measurements not specifically described	Qualified Accept for Standley Reject for Mower Reject for Great Western
5	Data Review	Data review process prior to publication of document is unknown Level and depth of review not stated	Qualified Accept for Standley Reject for Mower Reject for Great Western
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of the data set Data qualifiers presented with data	
	B Comparability		
	C Representativeness		
	D Precision		
	E Accuracy		

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.13

INTERIM REPORT ON SAMPLING AND ANALYSIS OF SEDIMENTS AND CORES FROM GREAT WESTERN AND STANDLEY RESERVOIRS, DECEMBER 20, 1973

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report includes sample locations for site, however, data results cannot be correlated with all sample locations based on information provided in document. No data sets included, only data summary No interpretations of data useability No narrative describing why insufficient samples were taken for radionuclide analysis No correlation of gamma peaks listed in Table III with specific radionuclides Document not generated for use in risk assessment Interim report does not reference specific data sources for summary of analytical results	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or quality assurance project plan provided Maps provided with general locations of sample points Table IV does not provide locations of sampling points listed	Reject	
	B SOPs	The summary of previous data does not reference specific sediments or core collection or sediment sampling procedures	Reject	
	C Field and Analytical Records	No field logs or raw data available No chain of custody records selection and identification of sampling points not documented No documentation provided describing why certain samples were insufficient for analysis. No documentation for deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Analysis of radionuclide performed	Qualified Accept	
	B Non analytical	No field measurements available for site specific physical parameters	Reject	
4	Analytical Methods	Analytical methods not stated. Quality control measures not stated Replicate analysis not performed Counting instrument background values listed Method detection limit percent recovery, LLD, and MDA not stated Laboratories performing analysis not identified	Reject	
5	Data Review	Data review process prior to publication unknown Level of quality assurance/quality control review unknown	Reject	
6	Data Quality Indicators A Completeness	No explanation of inadequate sample designation for a number of sample locations Assumption is that 100 percent of samples collected were correctly analyzed No explanation as to why some sampling points identified on map do not have corresponding analytical data No data qualifiers presented with data Am, H^3, Pu, Sr, Co, and other radionuclides were analyzed	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	Since no sampling method was referenced, it would not be appropriate to directly compare the results of this report with other reports	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	Soil and sediment media were characterized.	Sampling	Qualified Accept
			Analytical	Reject
			Combined	Qualified Accept
	D Precision	No indication of field blanks, trip blanks, or internal standards collected Counting error not stated. Replicate analysis not performed.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	No percent recovery analysis performed No description of QA/QC data. No documented QA review	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.14

GREAT WESTERN RESERVOIR SEDIMENT CORE DATA GRAPHS, FEBRUARY 1985 DECEMBER 20, 1973

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	A cover letter is attached to the document that provides additional conclusions as to the origin of Pu in sediment. Sampling procedures are compared.	Qualified Accept	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan, or quality assurance project plan provided No site description, but site map provided with sample locations	Reject	
	B SOPs	Limited description of sampling design Procedures omitted.	Reject	
	C Field and Analytical Records	No field logs or raw data available No chain of custody records No documentation concerning deviation from sampling and analysis plan or standard operating procedures	Reject	
3	Data Sources A Analytical	Samples not analyzed for Am-241	Reject	
	B Non-analytical	No field measurement data available for site such as particle size, pH, clay content, porosity of soil, wind direction typography, etc.	Reject	
4	Analytical Methods	Specific sampling procedures and analytical methods not referenced Quality control measures not described Replicate analysis not performed Method detection limit, percent recovery, LLO and MDA not stated Laboratory performing analysis identified.	Reject	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of the data set No data qualifiers presented with data Am-241 not analyzed	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	The attached letter to the report indicates that a different sampling methodologies were used in this report.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	C Representativeness	The data may represent the actual concentrations of Pu in sediment but supporting documentation not provided.	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	D Precision	No field blanks, trip blanks, internal standards, or standard sediment analysis performed Replicate sampling not done Standard deviation included	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Percent recovery analysis not performed Description of minimum QA/QC data not included No documented QA review	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.15

PLUTONIUM LEVELS IN THE SEDIMENT OF AREA IMPOUNDMENTS ENVIRONS OF THE ROCKY FLATS PLUTONIUM PLANT FEBRUARY, 1975

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report includes only sediment sampling for Sites 200 202 No intrepetation of data useability No narrative summary describing specific sampling or analytical problems Document not generated for use in risk assessment.	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan or quality assurance project plan provided Detailed map of sampling locations provided.	Reject	
	B SOPs	No description of sampling design Procedures omitted.	Reject	
	C Field and Analytical Records	No field logs or raw data available Selection for process for sampling points not documented.	Reject	
3	Data Sources A Analytical	Analytical results reported by depth	Qualified Accept	
	B Non analytical	No field measurements data available for site, such as particle size, pH, clay content, porosity of soil, wind direction, topography, etc	Reject	
4	Analytical Methods	Analytical methods and procedures not referenced Quality control measurements not described Replicate analysis not performed Method detection limits, percent recovery, LLD and MDA not stated.	Reject	
5	Data Review	Data review process prior to publication of document unknown The timeliness, level and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data sets Assumption is that 100 percent of samples collected were correctly analyzed No data qualifiers presented with data	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	It seems that sample points taken here may be comparable sample points in other reports Coordinates not given Core and sediment sampling partially comparable to aquifer in other reports	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	C Representativeness	This data may reflect the concentrations of plutonium in sediment, but no other pathways have been characterized	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	D Precision	No field blanks, trip blanks, internal standards, or standard sediment sampling analysis was performed. Replicate analysis not performed. Data sets not included Counting error not stated.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Percent recovery analysis not performed Description of minimum QA/QC data not included No documented QA review No tracer to field samples to assure 100 percent recovery	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.16

SURVEY OF RESERVOIR SEDIMENTS, JUNE, 1974

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report includes only sediment sampling for Sites 200-202 No intrepetation of data useability No narrative summary describing specific sampling or analytical problems Document not generated for use in risk assessment.	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan sampling and analysis plan or quality assurance project plan provided Detailed map of sampling locations provided.	Reject	
	B SOPs	No description of sampling design Procedures omitted.	Reject	
	C Field and Analytical Records	No field logs or raw data available Selection for process for sampling points not documented.	Reject	
3	Data Sources A Analytical	Analytical results reported by depth	Qualified Accept	
	B Non analytical	No field measurements data available for site, such as particle size, pH, clay content, porosity of soil, wind direction, topography, etc	Reject	
4	Analytical Methods	Analytical methods and procedures not referenced Quality control measurements not described Replicate analysis not performed Method detection limits, percent recovery, LLD and MDA not stated.	Reject	
5	Data Review	Data review process prior to publication of document unknown The timeliness, level and depth of review not stated in document.	Reject	
6	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data sets Assumption is that 100 percent of samples collected were correctly analyzed No data qualifiers presented with data	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	It seems that sample points taken here may be comparable sample points in other reports Coordinates not given Core and sediment sampling partially comparable to aquifer in other reports	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	C Representativeness	This data may reflect the concentrations of plutonium in sediment, but no other pathways have been characterized	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	D Precision	No field blanks, trip blanks, internal standards, or standard sediment sampling analysis was performed. Replicate analysis not performed. Data sets not included Counting error not stated.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Percent recovery analysis not performed Description of minimum QA/QC data not included No documented QA review No tracer to field samples to assure 100 percent recovery	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.17

HISTORY AND EVALUATION OF REGIONAL RADIONUCLIDE WATER MONITORING

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Report includes only sediment sampling for Sites 200-202 No intrepetation of data useability No narrative summary describing specific sampling or analytical problems Document not generated for use in risk assessment.	Reject	
2	Documentation A WP/SAP/QAPjP	No work plan, sampling and analysis plan or quality assurance project plan provided Detailed map of sampling locations provided.	Reject	
	B SOPs	No description of sampling design Procedures omitted.	Reject	
	C Field and Analytical Records	No field logs or raw data available Selection for process for sampling points not documented.	Reject	
3	Data Sources A Analytical	Analytical results reported by depth	Qualified Accept	
	B Non-analytical	No field measurements data available for site, such as particle size, pH, clay content, porosity of soil, wind direction, topography, etc	Reject	
4	Analytical Methods	Analytical methods and procedures not referenced Quality control measurements not described Replicate analysis not performed Method detection limits, percent recovery, LLD and MDA not stated.	Reject	
5	Data Review	Data review process prior to publication of document unknown The timeliness, level and depth of review not stated in document.	Reject	
6.	Data Quality Indicators A Completeness	No indication if data collection and analysis problems affected the completeness of data sets Assumption is that 100 percent of samples collected were correctly analyzed No data qualifiers presented with data	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	B Comparability	It seems that sample points taken here may be comparable sample points in other reports Coordinates not given Core and sediment sampling partially comparable to aquifer in other reports	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	C Representativeness	Thus data may reflect the concentrations of plutonium in sediment, but no other pathways have been characterized	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	D Precision	No field blanks, trip blanks, internal standards, or standard sediment sampling analysis was performed. Replicate analysis not performed. Data sets not included. Counting error not stated.	Sampling	Reject
			Analytical	Reject
			Combined	Reject
	E Accuracy	Percent recovery analysis not performed Description of minimum QA/QC data not included No documented QA review No tracer to field samples to assure 100 percent recovery	Sampling	Reject
			Analytical	Reject
			Combined	Reject

[1] Decision Accept, Qualified Accept, Reject

TABLE A1.18

GREAT WESTERN RESERVOIR SPILLWAY
SEDIMENT SAMPLING PROGRAM
PHASE I AND II

Data Useability Criteria		Comments	Decision[1]	
1	Reports to Risk Assessor	Narrative summary included interpretation of data		
2	Documentation A WP/SAP/QAPjP	Sampling and analysis plan included QA referenced plan	Accept	
	B SOPs	SOPs included or referenced	Accept	
	C Field and Analytical Records	No field or raw data available Selection process for sampling points referenced.	Qualified Accept	
3	Data Sources A Analytical	Analytical results reported in pCi/g for Pu. An analysis performed with standard deviation statement.	Accept	
	B Non analytical	No field requirements dta available for site such as particle size, pH, clay content, porosity of soil, wind direction, topography, etc.	Reject	
4	Analytical Methods	Analytical methods and procedures referenced QC methods referenced replicate analysis performed Method detection limit, percent recovery, LLD and MDA stated	Accept	
5	Data Review	Data review process prior to publication of document is unknown The timeliness, level, and depth of review not stated in document.	Reject	
6	Data Quality Indicators	No indication of data collection and analysis problems affected the completeness of data sets Assumtion is that 100% of samples collected were correctly analyzed	Sampling	Reject
			Analytical	Reject
	A Completeness	No data qualifiers presented with data	Combined	Reject
	B Comparability	It seems that sample points taken here may be comparable to sample points in other reports Coordinates not given Core and sediment sampling partially comparable to aquifer in other reports	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	C Representativeness	This data may reflect the concentrations of plutonium in sediment, but no other pathways have been characterized	Sampling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept
	D Precision	Field blanks used Replicate analysis performed Counting error stated.	Sampling	Accept
			Analytical	Accept
			Combined	Accept
	E Accuracy	Description of QA/QC data referenced. No documented QA reviews	Samling	Qualified Accept
			Analytical	Qualified Accept
			Combined	Qualified Accept

[1] Decision Accept, Qualified Accept, Reject

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1.0 THE NATURE OF RISK ASSESSMENT

Regulatory actions are based on two distinct elements, risk assessment, the subject of this study, and risk management Risk assessment is the use of the factual base to estimate the potential health effects of possible exposure of individuals or populations to hazardous materials and situations Risk management is the process of weighing policy alternatives and selecting the most appropriate regulatory action, integrating the results of risk assessment with engineering data and with social, economic, and political concerns to reach a decision

Risk assessments contain some or all of the following four steps

- Hazard identification The determination of whether a particular chemical is or is not causally linked to particular health effects
- Dose-response assessment The determination of the relation between the magnitude of exposure and the probability of occurrence of the health effects in question
- Exposure assessment The determination of the extent of human exposure before or after application of remedial controls
- Risk characterization The description of the nature and often the magnitude of human risk, including attendant uncertainty

In each step, a number of decision points (components) occur where risk to human health can only be inferred from the available evidence Both scientific judgements and policy choices may be involved in selecting from among possible inferential bridges, therefore the term "risk assessment policy" is used to differentiate those judgements and choices from the broader social and economic policy issues that are inherent in risk management decisions

2.0 TERMINOLOGY

Despite the fact that risk assessment has become a subject that has been extensively discussed in recent years, no standard definitions have evolved, and the same concepts are encountered under different names The following sections discuss the various terms and components common to risk assessments and risk management studies

2 1 RISK ASSESSMENT AND RISK MANAGEMENT

Risk assessment is used to mean the characterization of the potential adverse health effects of human exposures to environmental hazards Risk assessments include several elements description of the potential adverse health effects based on an evaluation of results of epidemiologic, clinical, toxicologic, and environmental research, extrapolation from those results to predict the type and estimate the extent of health effects in humans under given conditions of exposure, judgements as to the number and characteristics of persons exposed at various intensities and durations; and summary judgements on the existence and overall magnitude of the public-health problem. Risk assessment also includes characterization of the uncertainties inherent in the process of inferring risk

The term risk assessment is often given narrower and broader meanings than adopted here For some observers, the term is synonymous with quantitative risk assessment and emphasizes reliance on numerical results A broader definition includes quantification, but also includes qualitative expressions of risk Quantitative estimates of risk are not always feasible, and they may be eschewed by agencies for policy reasons. Broader uses of the term also embrace analysis of perceived risks, comparisons of risks associated with different regulatory strategies, and occasionally analysis of the economic and social implications of regulatory decisions -- functions that are assigned to risk management

The term risk management is used to describe the process of evaluating alternative regulatory actions and selecting among them Risk management, which is carried out by regulatory agencies under various legislative mandates, is an agency decision-making process that entails consideration of political, social, economic, and engineering information with risk-related

information to develop, analyze, and compare regulatory options and to select the appropriate regulatory response to a potential chronic health hazard. The selection process necessarily requires the use of value judgements on such issues as the acceptability of risk and the reasonableness of the costs of control

2 2 RISK ASSESSMENT COMPONENTS

Risk assessment can be divided into four major steps hazard identification, dose-response assessment, exposure assessment, and risk characterization A risk assessment might stop with the first step, hazard identification, if no adverse effect is found or if an agency elects to take regulatory action without further analysis, for reasons of policy or statutory mandate For this site, the hazard identification, although incomplete, has definitely established that plutonium is present, and thus must continue through the subsequent steps

Of the four steps, hazard identification is the most easily recognized in the actions of regulatory agencies It is defined here as the process of determining whether exposure to an agent can cause an increase in the incidence of a health condition (cancer, birth defect, etc) It involves characterizing the nature and strength of the evidence of causation Although the question of whether a substance causes cancer or other adverse health effects is theoretically a yes-no question, there are few chemicals on which the human data are definitive Therefore, the question is often restated in terms of effects in laboratory animals or other test systems, e g , "Does the agent induce cancer in test animals?" Positive answers to such questions are typically taken as evidence that an agent may pose a cancer risk for any exposed humans Information from short-term in vitro tests and on structural similarity to known chemical hazards may also be considered

Dose-response assessment is the process of characterizing the relation between the dose of an agent administered or received and the incidence of an adverse health effect in exposed populations and estimating the incidence of the effect as a function of human exposure to the agent It takes account of intensity of exposure, age pattern of exposure, and possibly other variables that might affect response, such as sex, lifestyle, and other modifying factors A dose-response assessment usually requires extrapolation from high to low dose and extrapolation from

animals to humans A dose-response assessment should describe and justify the methods of extrapolation used to predict incidence and should characterize the statistical and biologic uncertainties in these methods

Exposure assessment is the process of measuring or estimating the intensity, frequency, and duration of human exposures to an agent currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment In its most complete form, it describes the magnitude, duration, schedule, and route of exposure, the size, nature, and classes of the human populations exposed, and the uncertainties in all estimates Exposure assessment is often used to identify feasible prospective control options and to predict the effects of available control technologies on exposure

Risk characterization is the process of estimating the incidence of health effects under the various conditions of human exposure described in exposure assessment It is performed by combining the exposure and dose-response assessments The summary effects of the uncertainties in the preceding steps are described in this step

The relations among the four steps of risk assessment and between risk assessment and risk management are depicted in Figure B-1 The type of research information needed for each step is also illustrated.

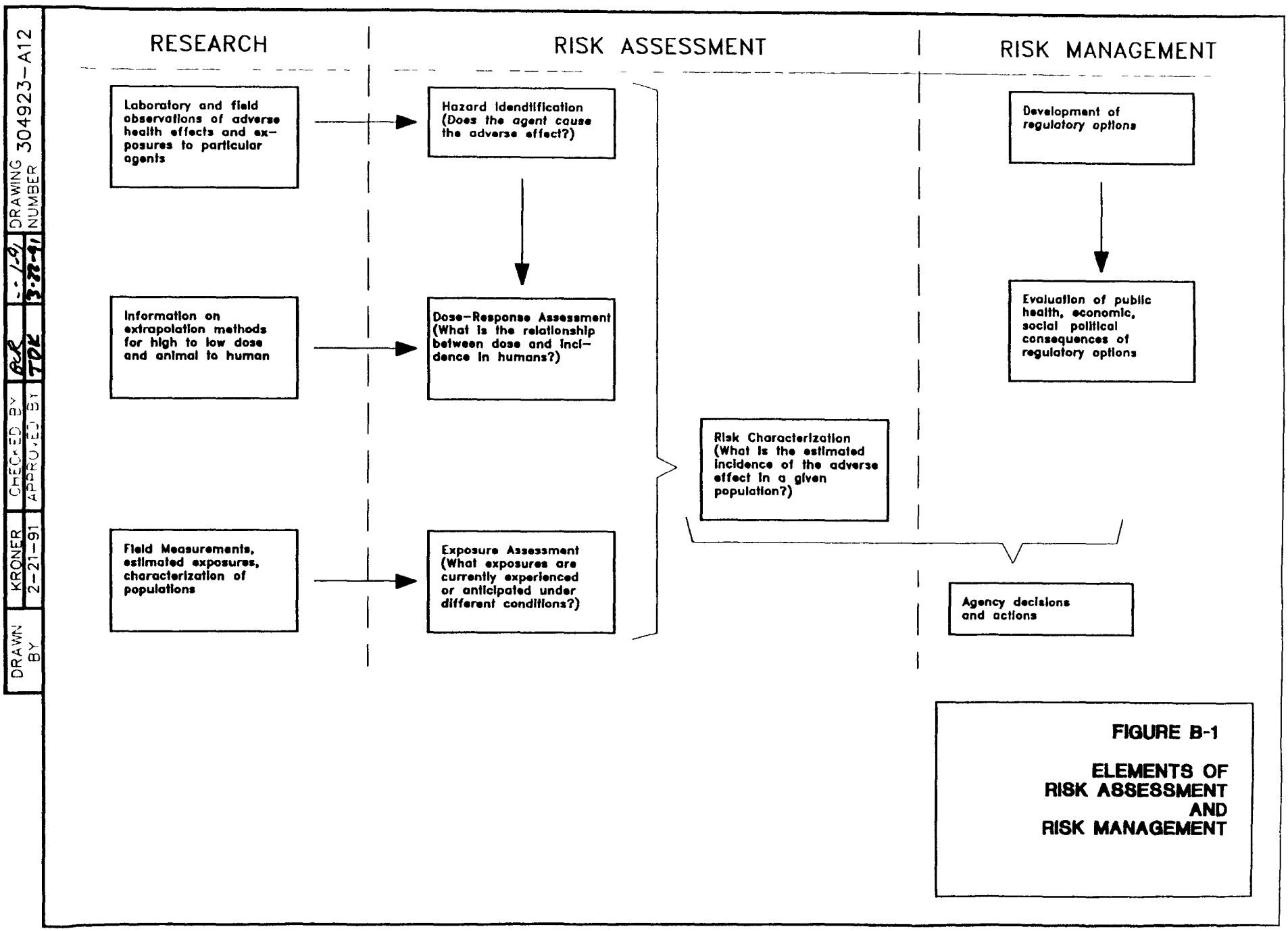

FIGURE B-1

ELEMENTS OF RISK ASSESSMENT AND RISK MANAGEMENT

3.0 SCIENTIFIC BASIS FOR RISK ASSESSMENT

3 1 STEP 1 HAZARD IDENTIFICATION

Although the risk assessment process as it is currently practiced by federal agencies for the estimation of carcinogenic risk contains several relatively new features, the scientific basis for much of the analysis done in risk assessment is well established This is especially true of the first step in the assessment process, hazard identification Four general classes of information may be used in this step epidemiologic data, animal-bioassay data, short-term studies, and comparisons of molecular structure

3 1 1 Epidemiologic data

Well-conducted studies that show a positive association between an agent and a disease are accepted as the most convincing evidence about human risk This evidence is, however, difficult to accumulate, often the risk is low, the number of persons exposed is small, the latent period between exposure and disease is long, and exposures are mixed and multiple Thus, epidemiologic data require careful interpretation Even if these problems are solved satisfactorily, the preponderance of chemicals in the environment has not been studied with epidemiologic methods, and we would not wish to release newly produced substances only to discover years later that they were powerful carcinogenic agents These limitations require reliance on less direct evidence that a health hazard exists

3 1 2 Animal Bioassay Data

The most commonly available data in hazard identification are those obtained from animal bioassays The interference that results from animal experiments are applicable to humans is fundamental to toxicologic research, this premise underlies much of experimental biology and medicine and is logically extended to the experimental observation of carcinogenic effects Despite the apparent validity of such inferences and their acceptability by most cancer researchers, there are no doubt occasions in which observations in animals may be of highly uncertain relevance to humans

Consistently positive results in the two sexes and in several strains and species and higher incidences at higher doses constitute the best evidence of carcinogenicity. More often than not, however, such data are not available Instead, because of the nature of the effect and the limits of detection of animal tests as they are usually conducted, experimental data leading to a positive finding sometimes barely exceed a statistical threshold and may involve tumor types of uncertain relation to human carcinogenesis Interpretation of some animal data may therefore be difficult Notwithstanding uncertainties associated with interpretation of some animal tests, they have, in general, proved to be reliable indicators of carcinogenic properties and will continue to play a pivotal role in efforts to identify carcinogens

3 1 3 Short-Term Studies

Considerable experimental evidence supports the proposition that most chemical carcinogens are mutagens and that many mutagens are carcinogens As a result, a positive response in a mutagenicity assay is supportive evidence that the agent tested is likely to be carcinogenic Such data, in the absence of a positive animal bioassay, are rarely, if ever, sufficient to support a conclusion that an agent is carcinogenic Because short-term tests are rapid and inexpensive, they are valuable for screening chemicals for potential carcinogenicity and lending additional support to observations from animal and epidemiologic investigations

3 1 4 Comparisons of Molecular Structure

Comparisons of an agent's chemical or physical properties with those of known carcinogens provides some evidence of potential carcinogenicity Experimental data support such associations for a few structural classes, however, such studies are best used to identify potential carcinogens for further investigation and may be useful in priority-setting for carcinogenicity testing

3 2 STEP 2 DOSE-RESPONSE ASSESSMENT

In a small number of instances, epidemiologic data permit a dose-response relation to be developed directly from observations of exposure and health effects in humans If epidemiologic data are available, extrapolations from the exposures observed in the study to lower exposures experienced by the general population are often necessary Such extrapolations introduce uncertainty into the estimates of risk for the general population Uncertainties also arise because

the general population includes some people, such as children, who may be more susceptible than people in the sample from which the epidemiologic data were developed

The absence of useful data is common for most chemicals being assessed for carcinogenic effect, and dose-response assessment usually entails evaluating tests that were performed on rats or mice The tests, however, typically have been designed for hazard identification, rather than for determining dose-response relations Under current testing practice, one group of animals is given the highest dose that can be tolerated, a second group is exposed at half that dose, and a control group is not exposed. (The use of high doses is necessary to maximize the sensitivity of the study for determining whether the agent being tested has carcinogenic potential) A finding in such studies that increased exposure leads to an increased incidence has been used primarily to corroborate hazard identification, that is, to show that the agent does indeed induce the adverse health effect

The testing of chemicals at high doses has been challenged by some scientists who argue that metabolism, or chemicals differ at high and low doses, i e., high doses may overwhelm normal detoxification mechanisms and provide results that would not occur at the lower doses to which humans are exposed. An additional factor that is often raised to challenge the validity of animal data to indicate effects in man is that metabolic differences among animal species should be considered when animal test results are analyzed Metabolic differences can have important effects on the validity of extrapolating from animals to man if, for example, the actual carcinogen is a metabolite of the administered chemical and the animals tested differ markedly from humans in their production of that metabolite A related point is that the actual dose of carcinogen reaching the affected tissue or organ is usually not known, thus, dose-response information, of necessity, is based on administered dose and not tissue dose Although data of these types would certainly improve the basis for extrapolating from high to low doses and from one species to another, they are difficult to acquire and often unavailable

Regulators are interested in doses to which humans might be exposed, and such doses usually are much lower than those administered in animal studies Therefore, dose-response assessment often requires extrapolating an expected response curve over a wide range of doses from one or

two actual data points In addition, differences in size and metabolic rates between man and laboratory animals require that doses used experimentally be converted to reflect these differences

3 3 STEP 3 EXPOSURE ASSESSMENT

The first task of an exposure assessment is the determination of the concentration of the chemical to which humans are exposed. This may be known from direct measurement, but more typically exposure data are incomplete and must be estimated Models for estimating exposure can be complex, even in the case of structured activity, as occurs in the workplace Exposure measurements made on a small group (e g , workers in a particular industrial firm) are often applied to other segments of the worker population

Exposure assessment in an occupational setting consists primarily of estimation of long-term airborne exposures in the workplace, however, because an agent may be present at various concentrations in diverse occupational settings, a census of exposures is difficult and costly to conduct. In the community environment, the ambient concentrations of chemicals to which people may be exposed can be estimated from emission rates only if the transport and fate processes are known. Alternative engineering control options require different estimates of the reduction in exposure that may be achieved. For new chemicals with no measurement data at all, rough estimations of exposure are necessary

Some chemical agents are of concern because they are present in foods or may be absorbed when a consumer product is used. Assessments of exposure to such agents are complicated by variations in diet and personal habits among different groups in the population Even when the amount of an agent in a food can be measured, differences in food storage practices, food preparation, and dietary frequency often lead to a wide variation in the amount of the agent that individuals ingest. Patterns of use affect exposure to many consumer products; for example, a solvent whose vapor is potentially toxic may be used outdoors or it may be used in a small, poorly ventilated room, where the concentrations of vapor in the air is much higher

4.0 USER'S GUIDE: RADIONUCLIDE CARCINOGENICITY

The Health Effects Assessment Summary (HEAST) Table C summarizes the cancer slope factors and unit risk values for selected radionuclides of potential concern at Superfund sites contaminated with radioactive materials Radionuclides specific to Sites 200-202 are listed in Table B 1 These values were calculated by the Office of Radiation Programs (ORP) and are intended for use by EPA risk assessors during human health risk assessments conducted as part of the Superfund remedial investigation/feasibility study (RI/FS) process HEAST users should apply these values as specified by the radiation risk assessment guidance provided in this section and in Chapter 10 of the Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Part A (EPA/540/1-89/002), which is available from the Center for Environmental Research Information at (513) 569-7562. As risk assessment methodologies are refined, slope factors and unit risk values will be revised and updated in Table B 1

EPA classifies all radionuclides as Group A carcinogens based on their property of emitting ionizing radiation and on the extensive weight of evidence provided by epidemiological studies of radiation-induced cancers in humans Data derived from both human studies and animal experiments are used by EPA to construct mathematical models of exposure, dose, and risk to estimate radionuclide slope factor values These models consider pathways of exposure, the distinct metabolic behavior of each element by compound and the radiological characteristics of each nuclide of concern, the time and duration of exposure, the radiosensitivity of each target organ in the body, the latency period for cancer expression in these organs, and the age and sex of individuals in the exposed population

Similar to chemical risk models, radiation models extrapolate cancer risks at low dose and dose rate exposures from risks observed at higher doses using non-threshold, linear dose-response relationships Because of the radiation risk models employed, slope factors for radionuclides are characterized as best estimates (i e , maximum likelihood estimates) of the age-averaged lifetime total excess cancer risk per unit intake or exposure HEAST users should consult Volume I of the Background Information Document for the Draft Environmental Impact Statement for

TABLE B.1

HEALTH EFFECTS ASSESSMENT SUMMARY TABLE
RADIONUCLIDE CARCINOGENICITY

Nuclide	ICRP Lung Class	GI Absorption Factor (F_1)	Slope Factor: Age-averaged lifetime excess total cancer risk per unit intake or exposure			Pathway-Specific Unit Risk: Age-averaged lifetime excess total cancer risk per unit daily intake or exposure for 70 years			
			Inhalation (pCi)[1]	Ingestion (pCi)[1]	Ground Surface (yr/[pCi/m^2])[1]	Air (pCi/m^3)[1]	Drinking Water (pCi/L)[1]	External Exposure (pCi/g)[1]	Soil Ingestion (pCi/g)[1]
Am 241	W	1 OE-03	4 OE-08	3.1E-10	1 6E 12	2.1E-02	1 6E-05	1 6E-05	8.4E-07
Pu-238	Y	1 OE-03	4 2E-08	2.8E 10	6 1E 14	2.1E-02	1 4E-05	5 9E-07	7 6E-07
Pu-239	Y	1 OE-04	4 1E-08	3 1E-11	2.6E-14	2.6E-02	1 6E-06	2.6E-07	8.4E-08
Pu-240	Y	1 OE-04	4 1E-08	3 1E-11	5 9E 14	2.1E-02	1 6E-06	5 9E-07	8 4E-08
Pu-241	Y	1 OE-03	2.9E 10	4 8E 12	0 0E+00	1 5E-04	2.5E-07	0 0E+00	1 3E-08
Pu-242	Y	1 OE-04	3 9E-08	3 0E-11	4 9E 14	2.1E-02	1 5E-06	4 8E-07	8 1E-08

Proposed NESHAPs for Radionuclides (EPA 520/1-89-005) for a more detailed discussion of EPA's current radiation risk assessment methodology

Quantitative carcinogenic factors listed in Table B 1 include the following

> slope factor = risk per unit intake of exposure = risk per pCi inhaled or ingested or as risk per year per pCi/m^2 due to external exposure
>
> pathway-specific unit risk = risk per unit concentration in air, drinking water or soil (external exposure) = risk per pCi/m^3 (air), risk per pCi/L (water), risk per pCi/g (external exposure), or risk pCi/g (soil ingestion)

Unit risk estimates for air, inhalation, drinking water, and soil ingestion pathways provided in Table C were calculated by multiplying the appropriate inhalation and ingestion slope factors by the inhalation rate (20 m^3/day), the water ingestion rate (2 L/day), or the soil ingestion rate (109 mg/day), respectively, and by multiplying all values by the total number of days in 70 years (i e , by the lifetime exposure = 365 days/yr x 70 yrs = 25,550 days) Hence

risk per pCi/m^3 (air)	=	slope factor (risk per pCi inhaled) x 20 m^3/day x 25,550 days
risk per pCi/L (water)	=	slope factor (risk per pCi ingested) x 2 L/day x 25,550 days
risk per pCi/g (soil) (soil ingested)	=	slope factor (risk per pCi ingested) x ([0 2 g/day x 1,825 days] + [0 1 g/day x 23,360 days])

The designations "D," "W," and "Y" presented under the heading "ICRP Lung Class" in Table C refer to the lung clearance times for inhaled particulate radionuclides expressed as days (D), weeks (W), or years (Y), as recommended by the International Commission on Radiological Protection (ICRP) Gaseous radionuclides, e g , Rn-222, are assigned to class "g " "GI Absorption Factors, f," are the fractional amounts of each radionuclide that may be absorbed from the gastrointestinal (GI) tract into blood following an oral intake The ICRP lung clearance rates and GI absorption factors provided in Table C are default values used by the EPA to calculate radionuclide slope factors for inhalation and ingestion exposures, respectively Application of values other than those specified in Table C will result in slope factors and unit risk estimates

different from those provided in the table At this time, EPA recommends that risk assessors should not replace or substitute for the default values listed

Values listed in Table C for external exposure are best estimates of the lifetime cancer risk due to the irradiation of an individual exposed to gamma-emitting radionuclides uniformly mixed in soil Unit risk estimates for this pathway were calculated by multiplying the appropriate ground surface slope factors by the effective surface density of soil (i e , 143 kg/m^2 = 0 10 m [soil depth] x 1 43x10^3 kg/m^3 [soil density]), and by multiplying all values by 70 years (i e , by the lifetime exposure) Hence,

risk per pCi/g (soil) = slope factor (risk per year per pCi/m^2) x 143 kg/m^2 x 10^3 (g/kg) x 70 years

To estimate risk-specific concentrations in air from the unit risk in air as presented in Table C, the specified level of risk is divided by the unit risk for air Hence, the air concentration (in pCi/m^3) corresponding to a best estimate of the increased lifetime cancer risk of $1x10^{-5}$ is calculated as follows

$$pCi/m^3 \text{ in air} = \frac{1x10^{-5}}{\text{unit risk in } (pCi/m^3)^{-1}}$$

Similarly, to estimate risk-specific concentrations in water and in soil (ingestion exposure), the specified level of risk is divided by the unit risk for drinking water or soil ingestion Hence, the water concentration (in pCi/L) corresponding to a best estimate of the increased lifetime cancer risk of $1x10^{-5}$ is calculated as follows

$$pCi/L \text{ in water} = \frac{1x10^{-5}}{\text{unit risk in } (pCi/L)^{-1}}$$

and the soil concentration (in pCi/g) corresponding to a best estimate of the increased lifetime cancer risk of $1x10^{-5}$ is calculated as follows

$$\text{pCi/g in soil (ingestion exposure)} = \frac{1x10^{5}}{\text{unit risk in } (\text{pCi/g})^{-1} \text{ (soil ingestion)}}$$

To estimate risk-specific concentrations in soil from the unit risk from external exposure as presented in Table C, the specified level of risk is divided by the unit risk for soil Hence, the soil concentration (in pCi/g) corresponding to a best estimate of the increased lifetime cancer risk of $1x10^{-5}$ is calculated as follows

$$\text{pCi/g in soil (external exposure)} = \frac{1x10^{5}}{\text{unit risk in } (\text{pCi/g})^{-1} \text{ (external exposure)}}$$

4 1 RISK CALCULATION - USE OF SLOPE FACTORS

The radionuclide slope factors in Table C of HEAST are the age-averaged lifetime excess total cancer risks per unit intake or exposure An estimate of the total lifetime excess cancer risk due to continuous internal lifetime exposure (i e , a 70-year average lifespan) to a radionuclide is therefore

$$R_L = (SF_L)\ (I)\ T_L)$$

where

R_L = total lifetime excess cancer risk
SF_L = HEAST radionuclide intake slope factor $(pCi)^{-1}$
I = annual radionuclide activity intake (pCi/yr)
T_L = 70-year lifetime exposure (years)

An estimate of the total lifetime excess cancer risk due to continuous external exposure to a radionuclide deposited on ground surfaces is

$$R_L = (SF_L)\ (C)\ (T)$$

where

R_L = total lifetime excess cancer risk
SF_L = HEAST radionuclide external exposure slope factor (yr - pCi)$^{-1}$
C = radionuclide concentration in soil (pCi/g)
T_L = 70-year lifetime exposure (years)

External slope factors do not include contributions from decay products In some cases, these contributions can be substantial and should be factored into the risk calculations For example, to estimate the total lifetime excess cancer risk due to continuous, lifetime external exposure to soil contaminated with Pu-239, and Pu-240 (assuming secular equilibrium) should be calculated as the summation of the risks contributed by Pu-240 and the decay product that emits photon radiation, such as Am-241

The content of slope factors for chemicals has been well established by toxicologists to quantify risks of chemical-induced cancer based on chemical intake-response curves EPA recently adopted this methodology to quantify radiation-induced cancer risks for radionuclides in HEAST, Table C This is novel for all radiological risk assessors The HEAST slope factors for radionuclides that are potential chemicals of concern at IHSS are presented in Table B 1 Before introducing EPA's methodology for radionuclide slope factors, it is necessary to describe the conventional approach to risk assessment. A description of internal exposure is presented because the calculation for this route of exposure is sufficient to furnish a clear paradigm of this standard methodology

4 2 DESCRIPTION OF CONVENTIONAL METHODOLOGY FOR RADIOLOGICAL RISK ASSESSMENT

Conventional risk estimation for chronic intake of a radionuclide involves two independent and separate steps The first step is to calculate the lifetime Committed Effective Dose Equivalent (CEDE) from the chronic lifetime intake of the radionuclide The CEDE is the weighted sum

of the total dose equivalent in target organ(s) deposited over the 50-year period following the intake of a radionuclide The absorbed dose in the target organ(s) is calculated using ICRP respiratory and GI tract models (ICRP, 1979) The second step is to estimate the risk associated with the lifetime CEDE

In the first step, the lifetime CEDE is obtained by multiplying the dose conversion factor (DCF), the CEDE per unit intake, by the total intake over the 70-year lifetime

$$CEDE_L = (I)(T_L)(DCF)$$

where

$CEDE_L$ = lifetime committed effective dose equivalent (mrem)
I = annual radionuclide activity intake (pCi/yr)
T_L = 70-year lifetime exposure (years)
DCF = dose conversion factor (mrem/pCi)

In the second step, the radiation-induced cancer risk is estimated using a risk coefficient (excess fatal cancers/mrem) to relate the lifetime CEDE (mrem) to the lifetime excess radiogenic cancer deaths ICRP Publication 26 (ICRP, 1977) and NCRP Publication 91 (NCRP, 1987) recommend the use of age-independent risk coefficients of 125×10^{-6} and 100×10^{-6} excess cancer deaths, respectively, for every unit CEDE (mrem) received to assess the lifetime excess fatal cancer risk Following is this recommendation

$$R_L = (RC_L)(CEDE_L)$$

where

R_L = lifetime excess fatal cancer risk
RC_L = lifetime fatal cancer risk per unit dose (mrem)$^{-1}$
$CEDE_L$ = lifetime committed effective dose equivalent (mrem)

Thus, based on the DCF that uses the 50-year dose commitment model, the CEDE from a constant chronic exposure is considered to be invariant over the individual's 70-year lifetime Because each step estimates cumulative dose and risk over 70 years, both the lifetime dose equivalent and the lifetime radiation-induced risks are obtained and can be utilized independently in the decision-making process

The following is a description of EPA's methodology to calculate the slope factors for both internal and external exposure to radionuclides

4.3 DESCRIPTION OF EPA'S METHODOLOGY FOR SLOPE FACTORS

4 3 1 Internal Exposure

There are three main steps involved in EPA's estimation of the risks due to exposure to unit intake of a radionuclide (1) the annual dose to susceptible organ(s) in each year of life is calculated, (2) the annual dose in each year of life is related to the age-dependent cancer risk, and (3) the lifetime cancer risk is obtained by summing the annual risks to a hypothetical cohort with an actuarial life table

In the first step, EPA calculates instantaneous high- and low-linear energy transfer (LET) absorbed dose rates and annual doses for each organ following one unit of inhaled or ingested radionuclide at a constant rate for a lifetime exposure The internal dose models (GI tract and lung models) that EPA uses to calculate doses are age-independent and are similar or identical to the models used in ICRP (1979, 1980, 1981)

In the second step, the risk of fatal cancer from each year's dose is calculated using age- and organ-specific risk models adapted from the BEIR III report (National Academy of Sciences [NAS] 1980) These risk models used by EPA are described in the following paragraphs

To project the number of radiation-induced leukemia and bone cancer fatalities, EPA uses an absolute risk model, a 2-year latency period, and a 25-year expression period. An absolute risk model predicts an absolute annual number of excess fatal cancers in future years in the case of a population exposed at a given age per unit dose

To estimate the number of fatalities resulting from other cancers, EPA uses a relative risk model, a 10-year latency period, and the remainder of an exposed person's lifetime as the expression period The relative risk model projects the currently observed percentage increase in annual fatal cancer risk per unit dose into future years (i e , the increase is proportional to the underlying [background] fatal cancer risk)

A central feature of this methodology is that it allows for other causes of death, so-called "competing risks" occurring within the latent period, in the estimation of lifetime radiation risks If an individual that had been exposed to radiation in a given population died either accidentally or from natural causes, before the cancers resulting from irradiation are expressed, this death would not be counted as a radiation-induced fatality A life table consists of data describing age-specific mortality rates from all these competing risks A life table consists of data describing age-specific mortality rates from all causes of death for a given population EPA uses mortality data from 1969 to 1971 United States population (National Center for Health Statistics [NCHS] 1975) in this risk estimation

To implement the lifetime risk estimation, EPA uses both absolute and relative risk models (as in the second step) in conjunction with actuarial life tables (as in the third step) to estimate the number of incremental fatalities in a given population, or "cohort," due to radiation-induced cancer in the reference organ as a result of the annual dose of each year of life The hypothetical EPA cohort consists of 100,000 persons born at the same time and all subject to the same competing risks of death throughout their lifetimes Radiation exposure is assumed to begin at birth and continue throughout the lifetime of each individual By applying the 1970 age-specific mortality data for all causes, this population of 100,000 persons is reduced for each year of life until all members of the cohort have died at 110 years

The incremental number of deaths in the cohort due to radiation-induced cancer for a given organ is estimated for each year using appropriate risk models and the calculated doses during that year and relevant preceding years The total number of incremental deaths for the cohort is obtained by summing the incremental number of deaths for each year over all organs for 110 years Therefore, the age-averaged lifetime excess fatal cancer risk per unit intake of the radionuclide is simply the average number of incremental deaths over the 110 years for each individual in the cohort

The radionuclide slope factors in HEAST, Table C, are the age-averaged lifetime excess total cancer risks, instead of fatal cancer risks, per unit intake Each slope factor has been calculated

by dividing the excess fatal cancer risks for the radionuclide by the mortality to incidence risk ratio for the type(s) of cancer induced by the radionuclide

4 3 2 External Exposure

EPA risk estimation for exposure to soil contaminated with gamma-emitting radionuclides is based on the scenario that an individual stands on an infinitely thick slab of soil with a uniform source concentration for his entire life (e g , a 70-year average life span) This EPA scenario involves three main steps

In the first step, the absorbed dose rate in air at 1 m above ground (which represents the average height of body organs for an individual standing on the ground) must be calculated To manage complicated calculations for photon attenuation and scattering soil, EPA simplifies the situation by assuming that instead of standing on the infinitely thick slab of soil, this individual stands on a smooth infinite plane source with a certain uniform surface concentration This surface concentration is obtained by confining the entire quantity of radioactivity within the top 10 cm of the soil slab to the very ground surface (zero depth) instead of uniformly dispersing it in the soil Consequently, EPA's hypothetical plane source with the zero-depth activity considers no soil shielding for the individual EPA's air and organ dose rate(s) calculation and the associated risk estimations, which will be discussed later, are therefore based on the hypothetical plane source model instead of the infinitely thick slab source model The conversion between the soil concentration (pCi/g) in the soil slab and the EPA hypothetical surface concentration can be obtained from the soil density of 1 43x10^3 (kg/m^3) and EPA's 10 cm soil depth concern One unit of soil concentration (1 pCi/g) in the slab would correspond to a hypothetical surface concentration in the following manner

$$1\ 43x10^5\ (pCi/m^2) = (pCi/g)x0\ 1\ (m)\ (depth)x1\ 43x10^3\ (kg/m^3)\ (density)x10^3\ (g/kg)$$

where 0 1 m (soil depth) x 1 43x10^3 kg/m^3 (soil density) = 143 kg/m^2 is the effective surface density of soil

One unit of surface concentration (1 pCi/m^2) on the soil surface would correspond to a concentration in the slab in the following manner

$$(1\ 43x10^5)^{-1} = 7x10^{-6}\ (pCi/g)$$

Thus, instead of calculating the air dose at 1 m above an infinitely thick soil slab source, EPA calculates the air dose rate at 1 m above a hypothetical infinite plane source If an individual is actually standing on a uniform slab source with a soil concentration of 1 pCi/g, EPA would report the 1 m air dose rate, his organ dose rate(s), and the associated cancer risks the same as those obtained from a plane source with a surface concentration of 1.43×10^5 pCi/m^2 On the other hand, EPA's report for the cancer risks from one unit of surface concentration (1 pCi/cm^2) is meant to be for the actual situation if the individual is exposed to a uniform slab source with a soil concentration of 7×10^{-6} pCi/g

In the second step, the absorbed rate in air must be converted to an organ dose rate The ratio of the organ dose rate has been calculated for various organs at various photon energies for the case of immersion in contaminated air Ideally, a separate set of the ratio values would be used for the angular and spectral distributions of incident photons from a uniform plane source Because these data are not available, EPA uses the same set of the ratio values for the air immersion case as for the ground surface case

In the third step, the annual dose in each year of life is related to the age-dependent cancer risk, and the lifetime cancer risk is obtained by summing the annual risks to a hypothetical cohort with an actuarial life table This step is a combination of steps (2) and (3) described in Section 4 3 1 The risk from each year's dose for each organ as obtained from step (2) is again calculated using EPA's life table concept in conjunction with the age- and organ-specific risk models The total number of incremental deaths from lifetime ground surface exposure in the 100,000-person cohort is also obtained by summing the incremental number of deaths for each year for 100 years The age-averaged lifetime excess fatal cancer risks per unit surface concentration of a radionuclide is the average number of incremental cancer deaths over the 110 years for each individual in the cohort Using the mortality-to-incidence risk ratio for the significant types of cancer that the external exposure may induce, EPA converts the fatal cancer risks to the total cancer risks as required for the slope factors

4 4 COMPARISON BETWEEN CONVENTIONAL AND EPA'S METHODOLOGIES FOR RISK ASSESSMENT

There are two principal differences between the conventional and EPA methodologies for radiological risk assessment First, the conventional risk estimation method produces an estimate of the risk of radiogenic cancers that are fatal and uses an age-independent risk coefficient The EPA risk estimation method produces an estimate of the risk of all cancer incidence and employs age-dependent risk coefficients Second, the conventional risk estimation method involves calculation of dose (CEDE) before calculation of cancer risk The EPA risk estimation methodology using HEAST slope factors estimates cancer risk directly from estimated radionuclide intake and bypasses calculation of CEDE Calculating the CEDE involves much less uncertain models than estimating radiogenic risk This is one main reason why the conventional risk assessment for a lifetime radiation exposure involves calculation of lifetime CEDE The conventional methodology separates the more certain step (lifetime CEDE calculation) from the less certain step (lifetime risk estimation) in the risk assessment process This enables the radiological risk assessors and remedial action decision makers to use both dose and risk parameters, taking into consideration the degree of confidence and certainty in each

The conventional method provides a fundamental parameter (i e , the lifetime CEDE from a chronic exposure to a radionuclide) that provides for comparison of the lifetime CEDE with established dose limits The lifetime risks associated with the lifetime CEDE depend on only one factor the risk per unit effective dose equivalent, which is subject to variation as new scientific information used to develop risk coefficients becomes available In EPA's methodology for estimating the lifetime radiogenic risk using slope factors, the step involving dose estimation is indistinct, therefore, the calculated lifetime dose equivalent is not available Thus, the radionuclide slope factors only provide the relationship between the lifetime radiogenic risk, which has a relatively high magnitude of uncertainty, and the radioactivity intake Superfund radiological risk assessors also need to calculate the lifetime CEDE as used in the conventional approach to furnish more scientific information for decision makers This is even more important at present because the slope factors for radionuclides are undergoing review and revision in HEAST, Table C

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1 0 SOME CONCEPTS OF RISK ASSESSMENT

The principal aim of radiation protection is to reduce the risk of detrimental health effects from radiation exposure Risk has been defined as the probability that a detrimental health effect will occur in an individual or population Mortality risk factors are helpful in identifying levels of risk associated with various activities and occupations Mortality risk factors are listed in Table C 1 for various events Almost every aspect of modern living exposes people to health risks This table lists the estimated risk of death to an individual from various human-caused and natural accidents In all cases the numbers listed in this table are only estimates based on the best guesses that can be made with our present knowledge

One of the reasons for the lack of understanding about risk is the manner in which risk data are typically presented Risk values are calculated based on mortality rates which are usually numbers of an order of 10^{-6} per year The average person has little experience with exponential notation and consequently little perception of the true significance of the data A 10^{-6} risk increases the chance of death by one person per million people exposed that risk

Risk is usually expressed as either absolute risk or relative risk When applied to radiation exposure an individual's absolute risk of mortality for a specific cause such as cancer is the excess risk from exposure added to his/her background risk of death from cancer. The term lifetime excess cancer risk is used to describe the portion of absolute risk resulting from exposure

The carcinogenic risk or the cancer risk factor (lifetime excess cancer risk) provides an estimate of the additional incidence of cancer that may be expected in a population exposed to a given contaminant. A risk of 10^{-5}, for example, indicates a probability of one additional case of cancer for every 100,000 people exposed A risk of 10^{-6} would be 1 case in 1 million people exposed (EPA 1985) On an individual basis the cancer risk factor describes the additional risk of death from cancer incurred as a result of exposure

TABLE C.1

PROBABILITY OF DEATH BY VARIOUS CAUSES[a]
(U S Population Average for 1978)

Cause	Total Number of Deaths	Individual Risk (Lifetime Probability)[b]
Accidents		
Motor Vehicle	52,411	1.28×10^{-2}
Air Transport	1,880	6.0×10^{-4}
Railway	602	2.0×10^{-4}
Falls	13,690	4.4×10^{-3}
Fire	6,163	2.0×10^{-3}
Drowning	5,784	1.9×10^{-3}
Industrial	5,168	1.7×10^{-4}
Electrocution	984	3.2×10^{-4}
Explosion	562	1.8×10^{-4}
Firearms	1,806	5.8×10^{-4}
Diseases		
Cardiovascular	964,000	3.1×10^{-1}
Malignancies (cancer)	396,720	1.3×10^{-1}
Influenza/Pneumonia	58,230	1.9×10^{-2}
Diabetes	33,800	1.1×10^{-2}
Natural Events		
Lightning	160	5.1×10^{-5}
Tornadoes	118[c]	3.8×10^{-5}
Hurricanes	90[d]	2.9×10^{-5}

Theoretical Calculated Generic Risk Assessment for Pu-239[e]	
Average Sediment Concentration	Individual Risk (Lifetime Probability)
0.1 pCi/g	1×10^{-9}
0.1 pCi/g	1×10^{-8}
1.0 Pci/g	1×10^{-7}
10.0 pCi/g	1×10^{-6}

[a] EPA, 1990b
[b] Based on total U S population
[c] 1953-75 average
[d] 1901-71 average
[e] Based on a conservative hybrid residential scenario

The carcinogenic risk posed by exposure to a radionuclide depends upon three factors dosage (estimated intake), the carcinogenic potency of the chemical (cancer slope factor) and the exposure duration

The carcinogenic potency of a substance depends, in part, upon its route of entry into the body (e g , ingestion, inhalation, or dermal) Therefore, cancer slope factors (CSFs) are classified according to the route of administration that is applicable to the experimental or epidemiological data from which they were derived. The EPA and other organizations have developed potency factors for the ingestion and/or inhalation routes for some carcinogens

The length of exposure to a radionuclide must also be taken into account in the calculation of carcinogenic risk since carcinogenic potency factors are based on long-term, low-dose exposure and carcinogenic risk is assumed to be proportional to dose

Absolute risk takes into account the added risk from exposure and background risk Site-specific absolute risk (AR) can thus be defined as

AR (cancer death) = Background Risk + Risk from Exposure to Plutonium

Based on the conservative assumptions presented in the generic risk assessment, (Tables C-3 through C-6) the added risk from a hybrid residential-recreational inhalation of resuspended sediment exposure scenario (ingestion of water, suspended sediments, and fish) from pathways in an area of subsurface sediments contaminated with plutonium can be calculated This would result in an increase of $1\ 2x10^{-9}$ risk for a plutonium concentration of 0 01 pCi/g, an increase of $1\ 2x10^{-8}$ risk for a concentration of 0 1 pCi/g, an increase of $1\ 2x10^{-7}$ risk for a concentration of 1 0 pCi/g, and an increase of $1\ 2x10^{-6}$ risk for a concentration of 10 pCi/g

To put this risk in perspective, the natural cancer mortality rate for the U S is about 20 percent However, for illustrative purposes we will use the values stated by EPA in Table C.1 of 13 percent (i e., 0 13) An individual's absolute risk of dying from cancer due to a 30-year

exposure to plutonium in sediments during a 70-year lifetime would increase from 0 13 to 0 130000001 at 0 01 pCi/g and 0 13000001 for 1 pCi/g based on generic risk assessment assumptions Table C 2 lists the overall increase in absolute risk resulting from long-term exposure to plutonium in a residential setting

exposure to plutonium in sediments during a 70-year lifetime would increase from 0 13 to 0 130000001 at 0 01 pCi/g and 0 13000001 for 1 pCi/g based on generic risk assessment assumptions Table C 2 lists the overall increase in absolute risk resulting from long-term exposure to plutonium in a residential setting

TABLE C.2

OVERALL INCREASE IN RISK FROM EXPOSURE TO PLUTONIUM IN SEDIMENTS

Plutonium Concentration in Soil	Added Risk	Background	Absolute Risk	Increased Risk from Plutonium
0 01 pCi/g	$1\ 2x10^{-9}$	$1\ 3x10^{-1}$	130000001	0 0000009 percent
0 1 pCi/g	$1\ 2x10^{-8}$	$1\ 3x10^{-1}$	13000001	0 000009 percent
1 0 pCi/g	$1\ 2x10^{-7}$	$1\ 3x10^{-1}$	1300001	0 00009 percent
10 pCi/g	$1\ 2x10^{-6}$	$1\ 3x10^{-1}$	130001	0 0009 percent

2.0 GENERIC RISK CHARACTERIZATION

The EPA has requested that a generic risk characterization be developed to assist the reader in placing the potential risk from plutonium in soils in perspective Two EPA documents were principally utilized to obtain general emission, transport, and human uptake values The two documents were the "Transuranic Elements," EPA 520/1-90-015 and 016, June 1990, U S EPA Air and Radiation Programs, and the "Exposure Factors Handbook," EPA/600/8-89/043, May 1989, U S EPA Office of Health and Environmental Assessment These values were then used to perform calculations based on the formulas found in Chapter 10 of the Risk Assessment Guidance (RAG) for Superfund Human Health Evaluation Manual, Part A, Interim Final, U S EPA Office of Emergency and Remedial Response, September 1989 In addition, the Health Effects Assessment Summary Table (HEAST) was utilized to calculate pathway-specific risk The dispersion and modeling used in the generic risk assessment is taken from Cowherd (1984) for the PM_{10} emission rate estimation, and Turner (1970) for the atmospheric dispersion estimation

For estimation of PM_{10} emissions from vehicle traffic over unpaved surfaces, the following equation has been used in this assessment

$$E_{10} = 0\,85 \left(\frac{s}{10}\right) \left(\frac{S}{24}\right)^{0\,8} \left(\frac{W}{7}\right)^{0\,3} \left(\frac{w}{6}\right)^{1\,2} \left(\frac{365-p}{365}\right) \quad (4\text{-}7)$$

where E_{10} = PM_{10} emission factor, i e , the quantity of PM_{10} emissions from an unpaved road per vehicle-kilometer of travel (kg/VKT)
s = silt content of road surface material (percent)
S = mean vehicle speed (km/hr)
W = mean vehicle weight (Mg)
w = mean number of wheels
p = number of days with at least 0 25 mm (0 01 in) of precipitation per year

The atmospheric dispersion estimation uses the following standard assumptions

- The plume spread has a Gaussian distribution in both the horizontal and vertical planes

- Uniform emission rate occurs

For this ground level source with no effective plume rise the following equation has been used in this assessment

$$\chi(X,0,0,0) = \frac{Q}{\pi \delta_y \delta_z \mu}$$

where X = downwind distance
χ = mean concentration
$\delta_y \delta_z \mu$ = standard deviation of plume concentration in the vertical and horizontal planes
μ = mean windspeed affecting plume

Plant uptake coefficients were cited by Burley (EPA, 1990b) These coefficients depend on conservative assumptions, and may overestimate the risk from ingestion presented in Baes, 1984 As stated previously (Section 4 6 2), although americium is potentially more mobile in the environment, and more readily bioconcentrated, it is not included in this generic risk assessment due to the inherent uncertainty of the actual concentrations at IHSS 199

2 1 EXPOSURE PATHWAYS

The generic risk assessment uses human uptake values published in previously cited EPA documents

The following exposure pathways have been retained in the generic risk assessment because of their potential to be available to human receptors based on the current and future land use condition of residential home setting

- Water ingestion of soluble plutonium
- Water ingestion of suspended plutonium
- Ingestion of aquatic species

- The recreational scenario retains the pathways listed above with the additional pathways of

  - Ingestion of plutonium in soil as exposed sediments
  - Inhalation of resuspended soil-sediment
  - Water ingestion of soluble plutonium
  - Water ingestion of suspended plutonium

2 2 EXPOSURE PATHWAY ASSUMPTIONS

In calculating risks to the general public in this report, the estimates of exposure are performed considering an appropriate individual that is presumed to remain at the point of specific potential exposure (0 01 pCi/g, 0 1 pCi/g, pCi/g, 10 pCi/g) at all times of their lifetimes -- 24 hours per day, 365 days per year, for 30 years -- and makes ordinary use of the contaminated media to the greatest extent possible For example, this hypothetical individual could breath only air at the specified contamination level on-site boundary, or ingest water while boating or swimming All drinking water is assumed to be provided directly from the lake/reservoirs, and no filtration is performed Thus, the estimate of exposure or risk to the general public is conservative and approximates the reasonable maximum exposure scenario (RME) identified by EPA guidance

Intakes of plutonium have been estimated on the basis of the RME scenarios for two current land use conditions The RME is defined by the EPA (1989) as "the highest exposure that is reasonably expected to occur at the site " This concept is also set forth in EPA's preamble to the adoption of the NCP In the preamble, the EPA explains that the concept of RME is designed to include exposures that can be reasonably expected to occur; though conservatively biased, it does not focus on worst-case exposure assumptions Only potential exposures that are likely to occur are to be included in the assessment of exposures The EPA further cautions against the use of unrealistic exposure scenarios and assumptions The RME is the product of factors that are an appropriate mixture of values that are conservative in that they tend to overestimate risk, but they are within a plausible range of potential exposure

Parameters that were common for all scenarios were used in the calculation of risk as follows

1 Current land use scenario of recreation occurring at the reservoir and lake

2 On-site concentration of plutonium in transport media does not increase nor decrease over time

3 An on-site air intake of 10 cubic meters per day for a 70 Kg adult received over a 40-year duration

4 A water intake of two-liters per day taken unfiltered from the lake/reservoir for a duration of 30 years

5 An average soil intake rate of 120 mg per day for a 70 Kg adult received over a 40-year lifetime

6 A plutonium in sediment bioavailability of 100 percent based on the soil-sediment ingestion and foodstuff pathway

7 A cancer slope factor of 3 $1x10^{11}$/pCi ingested, and a slope factor of 4 $1x10^{-8}$/pCi inhaled

Table C 3 details the major assumptions used in the generic risk assessment for plutonium in sediments

The major assumptions identified in Table C 3 have been combined to form one of three different exposure scenarios as follows

1) The residential facet The scenario reflects an exposure setting in which an individual consumes water and aquatic species from the affected water Ingestion of water occurs daily and ingestion of aquatic species occurs periodically The period of exposure is 30 years 30 years represents the upper 90% confidence limit on individual residence in a single location (EPA, 1989)

2) The recreational facet This scenario reflects an exposure setting in which an individual utilizes the lake for recreational purposes such as swimming, boating, and fishing Exposure in the recreational facet is assumed to occur twice weekly during the warm weather months (April-October) for forty-years

3) The hybrid residential-recreational exposure scenario Combining the residential and recreational facets in thisõ manner reflects exposure to an individual through both scenarios The hybrid residential-recreational exposure scenario could be applicable to an individual living near the lake

Table C 4 summarizes the intermediate transfer coefficients employed in the calculations provided in the spreadsheets located in Attachment 1, and Figure C-1 and Figure C-2 provide a graphic

depiction of the exposure assessment models to complete the estimated lifetime excess cancer risk for the generic risk assessment

TABLE C.3

MAJOR ASSUMPTIONS USED IN THE GENERIC RISK ASSESSMENT FOR PLUTONIUM IN SEDIMENTS AND SOILS

Current and Future Use (Residential Facet 30-year Period)		
Exposure Pathway	**Variable**	**RME[b]**
Ingestion of Suspended Sediments	Exp[a] Duration	30 years
Ingestion of Drinking Water	Exp Duration Intake	30 years 2 liters/day
Ingestion of Aquatic Species	Exp Duration Intake	30 years 195 gr/day

Current and Future Use (Recreational Facet 40-year Period)		
Exposure Pathway	**Variable**	**Conservative**
Inhalation of Airborne Particulate	Exp Duration Exp Frequency Leeward Wind Fraction	40 years 56 day/year 0 4
Soil Ingestion	Exp Duration Exp Frequency Intake	40 years 56 day/year 120 mg/day
Incidental Ingestion of Water	Exp Duration Intake	40 years 0 2 liters/day

[a] EXP - exposure
[b] RME - Reasonable Maximum Exposure
[c] Based on long-term wind patterns near Rocky Flats Plant

Review of Table C 5 suggests that the added lifetime excess cancer risk for an individual exposed through either the residential or recreational facets independently could range from 7 0 E-10 (Residential facet at 0 01 pCi/gram) to 4 6 E-7 (Recreational facet at 10 pCi/gram)

Inspection of Table C 6 indicates that under the conditions of the hybrid residential-recreational exposure scenario the added lifetime excess risk could range from 1 2 E-9 to 1 2 E-6 Table C 6 also indicates that, for the case where the same sediment concentration is applied to both facets (residential and recreational), the residential facet contributes approximately 60% of the added lifetime excess cancer risk and approximately 40% is attributable to exposure resulting from the recreational facet

Figure C-3 provides a graphical presentation of estimated, generic lifetime excess cancer risk estimates for the residential and recreational facets A generic graphical presentation of lifetime excess cancer risk versus sediment concentration for the hybrid residential-recreational exposure scenario is provided on Figure C-4

3.0 SUMMARY

The generic risk calculations presented above for the various conditions of exposure indicate that all calculated lifetime excess cancer risks are within or below EPA's 1 0 E-4 to 1 0 E-6 range of acceptable risk This generic assessment suggests that no imminent health risk would result from exposure produced from 239 Pu sediment concentrations in the range of 0 01 pCi/gram to 10 pCi/gram

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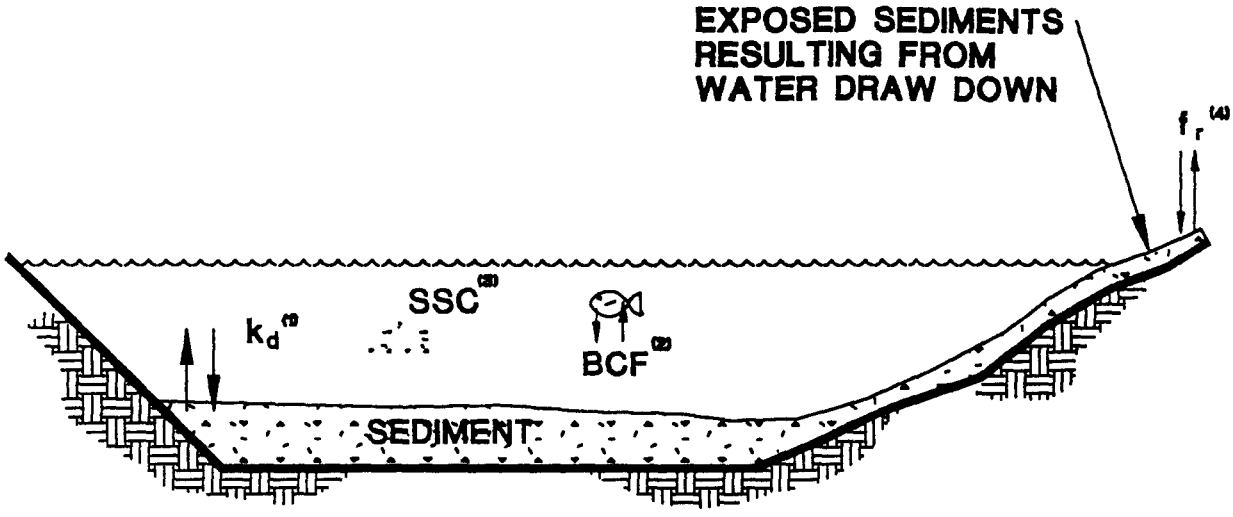

(1) k_d = $\frac{\text{Concentration - Sediments}}{\text{Concentration - Aqueous}}$ (ml/g)

(2) BCF = $\frac{\text{Concentration - Fish tissue}}{\text{Concentration - Aqueous}}$ (ml/g)

(3) SSC = Suspended Sediment Concentration

(4) f_r = $\frac{\text{Atmospheric Concentration, pCi/m}^3}{\text{Surface Concentration pCi/m}^2}$

Intermedia Transfer Factors

k_d (5)	BCF (6)	Resuspension (7)	Suspended Sediment Concentration
13 6(x10^{-4})	10ml/g	Resuspension Factor (fr)= 10^{-9}/meter	20 mg/l

(5) Conservative estimate from the aggregate range of literature and empirical values of k_d for plutonium in freshwater systems

(6) ATSDR, 1990

(7) Cember, 1983
Langer, 1989

FIGURE C 1

GENERIC CONCEPTUAL MODEL

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	APPROVED BY	
	CJR 6-12-91	

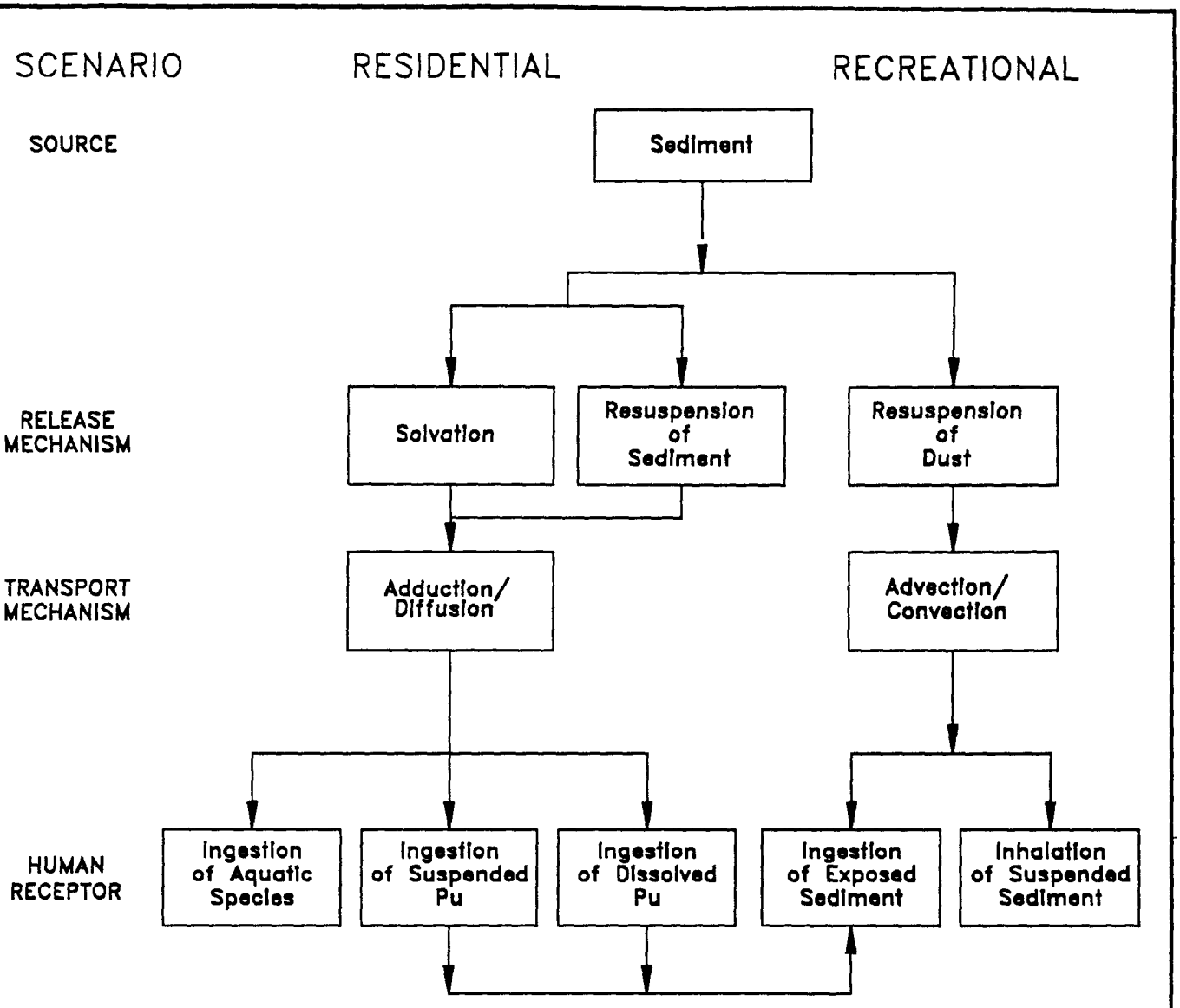

FIGURE C 2

GENERIC CONCEPTUAL EXPOSURE PATHWAY ASSESSMENT

TABLE C.4

SUMMARY OF Kd ESTIMATION TECHNIQUE

I. Literature Values

Source	Reported Kd ml/gr (10^{-4})	Aggregate	Reference	Summary Kd, ml/gr (10^{-4})	
Hudson River	5-60 4-30	32 5 17	Watters 1983	Mean Median	22 5 23 1
Lake Michigan	6.7	6 7	Watters 1983	75%	32 5
Lake Washington	33	33	Watters 1983	25%	17
Savannah River	4 2-42	23 1	Watters 1983	Std. Deviation Coef Vav	11 1 0 49

II Generic Estimates (1)

Source	Generic Estimate (10^{-4}) (1)	Description (2)	Summary, Concentration Ratios (10^{-4})
Standley Lake	1 36	Mean Sediment/Mean Aqueous	Mean of Standley and Great Western Reservoirs = 18 2
Great Western Reservoir	35.1	Mean Sediment/Mean Aqueous	

III Notes

(1) These generic Kd estimate are based on simple ratios of concentrations They are **not** derived from recognized scientific methods and should be used with professional scrutiny The basic data has been classified as not suitable for performing quantitative risk assessment.

(2) Sediment data source. Lammering, M.W , 1975, NTIS, PB-255572
Water data source Rockwell International, 1988, Rocky Flats Plan Site Environmental Report for 1989

TABLE C.5

RISK CHARACTERIZATION FOR CONSERVATIVE SCENARIOS

Conservative Current and Future Use (Residential) Scenario					
	Hypothetical 239 Pu Sediment Concentrations				Percent Contribution
Pathway	0 01 pCi/g	0 1 pCi/g	1 0 pCi/g	10 pCi/g	
Ingestion water soluble plutonium	5 0E-10	5 0E-09	5 0E-08	5 0E-07	71 4
Ingestion of water suspended plutonium	1 4E-10	1 4E-09	1 4E-08	1 4E-07	19 4
Ingestion of Aquatic Species	6 4E-11	6 4E-10	6 4E-09	6 4E-08	9 2
Total Risk.	7 0E-10	7 0E-09	7 0E-08	7 0E-07	100

Conservative Current and Future Use (Recreational) Exposure Scenario					
	Hypothetical 239 Pu Soil Concentrations				Percent Contribution
Pathway	0 01 pCi/g	0 1 pCi/g	1.0 pCi/g	10 pCi/g	
Ingestion of plutonium soil as exposed sediments	8 3E-11	8 3E-10	8 3E-09	8 3E-08	1 6
Inhalation of resuspended soil-sediment	3 7E-10	3 7E-09	3 7E-08	3 7E-07	98 2
Ingestion of water soluble plutonium	1 0E-11	1 0E-10	1 0E-09	1 0E-08	0 2
Ingestion of water suspended plutonium	2.8E-12	2.8E-11	2.8E-10	2.8E-09	0 1
Total Risk.	4 6E-10	4 6E-09	4 6E-08	4 6E-07	100

TABLE C.6

RISK CHARACTERIZATION FOR CONSERVATIVE HYBRID-RESIDENTIAL RECREATIONAL SCENARIO

Pathway	Hypothetical Pu-239 Sediment Concentrations				Percent Contribution
	0 01 pCi/g	0 1 pCi/g	1 0 pCi/g	10 pCi/g	
Residential Facet	7 0E-10	7 0E-9	7 0E-8	7 0E-7	60 1
Recreational Facet	4 6E-10	4 6E-9	4 6E-8	4 6E-7	39 9
Hybrid Residential-Recreational	1 2E-9	1 2E-8	1 2E-7	1 2E-6	100

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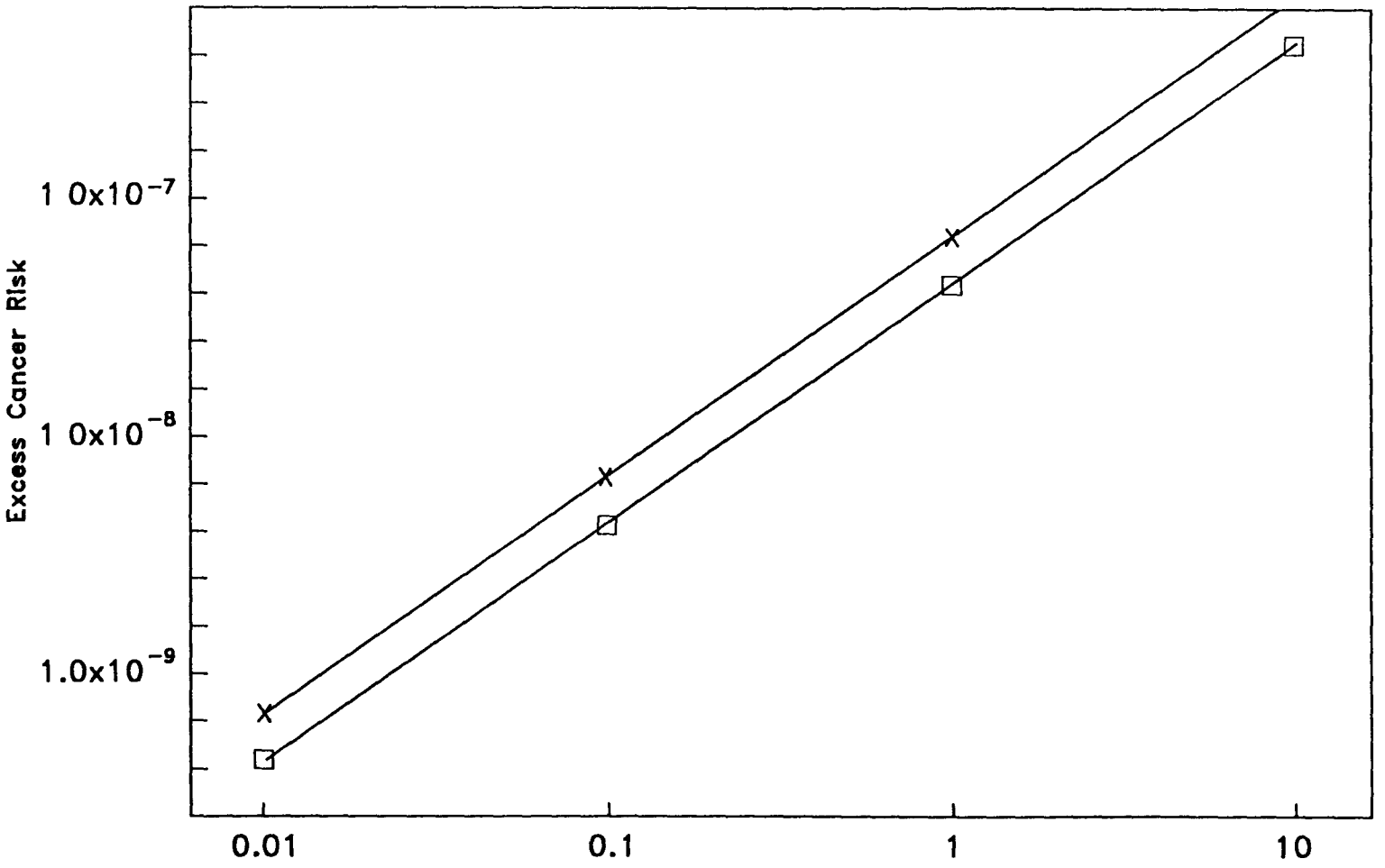
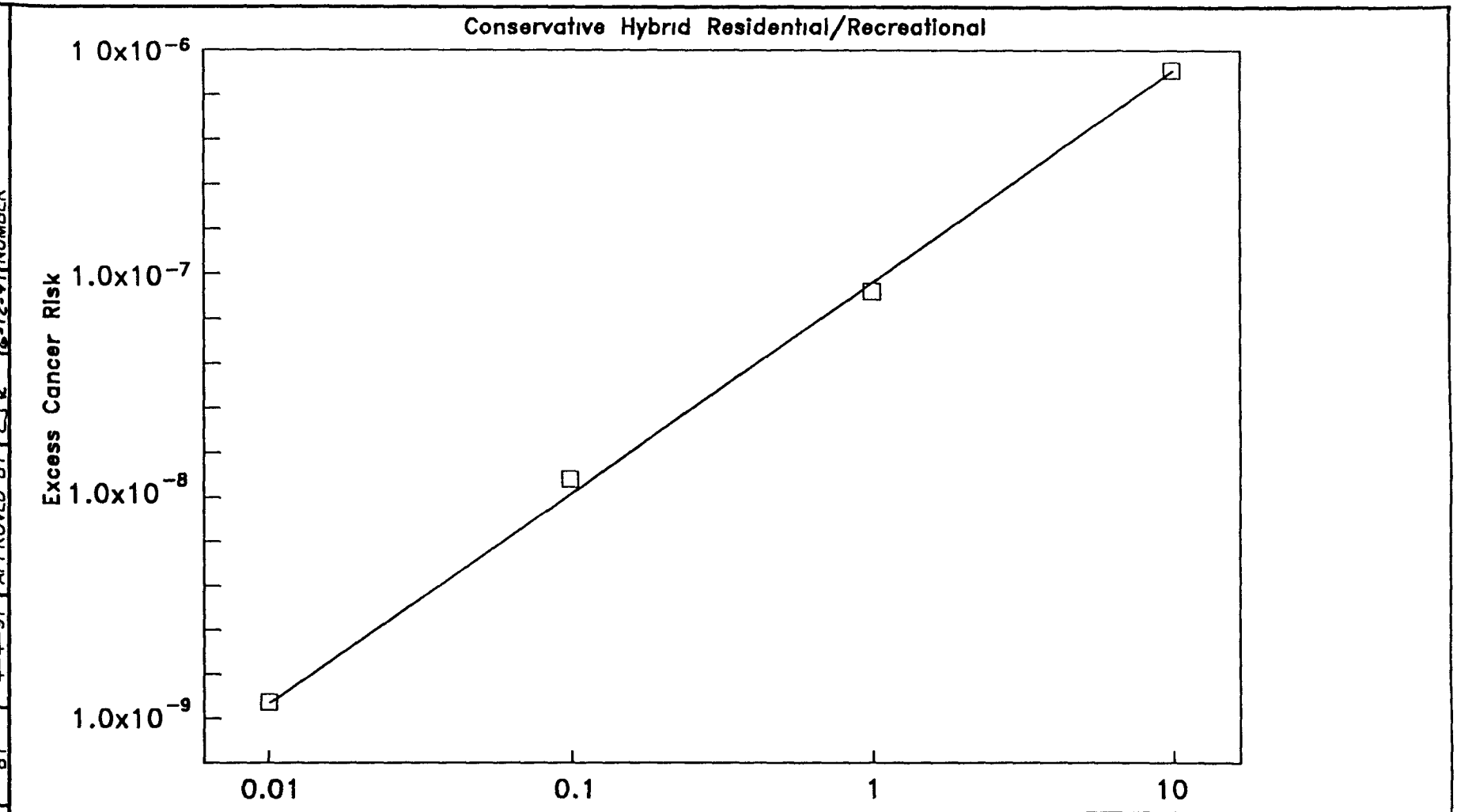


FIGURE C 3

EXCESS CANCER RISK FOR PU-239 IN SEDIMENTS

CONSERVATIVE RESIDENTIAL/ RECREATIONAL MODEL

Risk Calculations based on values taken from
EPA Exposure Factors Handbook, EPA/600/8-889/043, May 1989



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		APPROVED BY	CJR 6-12-91	

FIGURE C 4

EXCESS CANCER RISK FOR PU-239 IN SEDIMENTS

CONSERVATIVE HYBRID RESIDENTIAL/ RECREATIONAL MODEL

Risk Calculations based on values taken from
EPA Exposure Factors Handbook, EPA/600/8-889/043, May 1989.

This spreadsheet is intended to calculate Generic Estimates of Lifetime Excess Cancer Risk (LECR)
The technique is based upon EPA's approach presented in Risk Assessment Guidance for Superfund (RAGS, 1989)
Conservative generic assumptions are employed to reflect biased, upper-bound LECR estimates
Other computational techniques are also applicable and may produce different estimates of LECR
Caution should be observed when applying any of the LECR estimates from this spreadsheet
to site-specific conditions

June 12, 1991 Version 3

Residential Scenario

I Ingestion of Soluble Species

Variable	Unit	Parameter	pCi/gr 0 01	pCi/gr 0 1	pCi/gr 1	pCi/gr 10
Concentration	pCi/l		0 0007	0 007	0 07	0 74
Intake	l/day	2				
Exp Frequency	day/yr	365				
Exp Period	yrs	30				
Total exposure	pCi		16	161	1610	16103
Dose/Resp Factor	/pCi	3 1E-11				
L E C R	unitless		5 0E-10	5 0E-09	5 0E-08	5 0E-07
Log L E C R			-9 3E+00	-8 3E+00	-7 3E+00	-6 3E+00

Computation of Caq from Csed

Kd= Csed /Caq Unit of Kd= ml/gram

Kd= Media	13600 unit					
Sediment	pCi/gr	0 01	0 1	1	10	
Aqueous	pCi/l	0 0007	0 0074	0 074	0 735	

Example
(1 0 pCi/gr)/(13800 ml/gr)(1000 ml/l)=0 074 pCi/l

II Ingestion of Suspended Species

Variable	Unit	Parameter	pCi/gr	pCi/gr	pCi/gr	pCi/gr
			0 01	0 1	1	10
Concentration	pCi/l		0 0002	0 002	0 02	0 2
Intake	l/day	2				
Exp Frequency	day/yr	365				
Exp Period	yrs	30				
Tot Susp Solids	mg/l	20				
Total exposure	pCi		4 38	43 8	438	4380
Dose/Resp Factor	/pCi	3 1E-11				
L E C R	unitless		1 4E-10	1 4E-09	1 4E-08	1 4E-07
Log L E C R			-9 9E+00	-8 9E+00	-7 9E+00	-6 9E+00

Assume a nominal 20 mg/l total suspended solids concentration

III Ingestion of Aquatic Species

Variable	Unit	Parameter	pCi/gr 0 01	pCi/gr 0 1	pCi/gr 1	pCi/gr 10
Aqueous Concentration	pCi/l		0 0007	0 007	0 07	0 74
Tissue Concentration	pCi/gr		7 4E-06	7 4E-05	7 4E-04	7 4E-03
Intake	gr/day	195				
Exp Frequency	day/yr	48				
Exp Period	yrs	30				
BCF	ml/gr	10				
Total exposure	pCi		2 06	20 65	206 47	2064 71
Dose/Resp Factor	/pCi	3 1E-11				
L E C R	unitless		6 4E-11	6 4E-10	6 4E-09	6 4E-08
Log L E C R			-1 02E+01	-9 2E+00	-8 2E+00	-7 2E+00
Summation						
L E C R			7 0E-10	7 0E-09	7 0E-08	7 0E-07
Log L E C R			-9 1555370	-8 15553	-7 15553	-6 15553

Residential Exposure Route Risk Summary

Exposure Route	Est LECR	% Contribution
Soluble Species Ingestion	5 0E-10	71 4%
Suspended Species Ingestion	1 4E-10	19 4%
Fish Ingestion	6 4E-11	9 2%
Total	7 0E-10	100 0%

Recreational Scenario

I Ingestion of Soluble Species (Swimming/Boating)

Variable	Unit	Parameter	Sediment pCi/gr	Sediment pCi/gr	Sediment pCi/gr	Sediment pCi/gr
			0 01	0 1	1	10
Concentration	pCi/l		0 0007	0 007	0 07	0 74
Intake	l/day	0 2				
Exp Frequency	day/yr	56				
Exp Period	yrs	40				
Total exposure	pCi		0 33	3 3	32 9	329 4
Dose/Resp Factor	/pCi	3 1E-11				
L E C R	unitless		1 0E-11	1 0E-10	1 0E-09	1 0E-08
Log L E C R			-1 1E+01	-1 0E+01	-9 0E+00	-8 0E+00

II Ingestion of Suspended Species (Swimming/Boating)

Variable	Unit	Parameter	Sediment pCi/gr 0 01	pCi/gr 0 1	pCi/gr 1	pCi/gr 10
Concentration	pCi/l		0 0002	0 002	0 02	0 2
Intake	l/day	0 2				
Exp Frequency	day/yr	56				
Exp Period	yrs	40				
Tot Susp Solids	mg/l	20				
Total exposure	pCi		0 09	0 90	8 96	89 6
Dose/Resp Factor	/pCi	3 1E-11				
L E C R	unitless		2 8E-12	2 8E-11	2 8E-10	2 8E-09
Log L E C R			-1 2E+01	-1 1E+01	-9 6E+00	-8 6E+00

Assume a nominal 20 mg/l total suspended solids concentration

Summation Water Routes			1 3E-11	1 3E-10	1 3E-09	1 3E-08
Log L E C R			-10 886412	-9 88641	-8 88641	-7 88641

III Ingestion of Chemicals in Exposed Sediment *
(Shoreline Activities, Fishing/Hiking)

Variable	Unit	Parameter	pCi/gr	pCi/gr	pCi/gr	pCi/gr
			0 01	0 1	1	10
Concentration	pCi/gr		0 01	0 1	1	10
Intake (40 Yr Avg)	mg/day	120				
Exp Frequency	day/yr	56				
Exp Period	yrs	40				
Exposure period intake	pCi		2 688	26 88	268 8	2688
Dose/Resp Factor	/pCi	3 1E-11				
L E C R	unitless		8 3E-11	8 3E-10	8 3E-09	8 3E-08
Log L E C R			-1 0E+01	-9 1E+00	-8 1E+00	-7 1E+00

IV Local Inhalation of Resuspened Sediment *
(Shoreline Activities, Fishing/Hiking)

Variable	Unit	Parameter	pCi/gr 0 01	pCi/gr 0 1	pCi/gr 1	pCi/gr 10	
	pCi/m^2						
Depth for Resuspension	cm	1					Conventional
Resuspension Factor	/m	1 0E-08					Cember, 1983/Langer, 1989
Soil Density	gr/cm^3	1					Conventional
Fractional Leeward Wind	unitless	0 4					Maximum fraction wind blows in a direction
Concentration	pCi/m^3		0 000001	0 00001	0 0001	0 001	
Intake (8 Hr /Day)	m 3/day	10					
Exp Frequency	day/yr*	56					** NOAA for Stapleton
Exp Period	yrs	40					30 Yr Residence + 10
Exposure period intake	pCi		0 0224	0 224	2 24	22 4	
Dose/Resp Factor	/pCi	4 1E-08					
L E C R	unitless		3 7E-10	3 7E-09	3 7E-08	3 7E-07	
Log L E C R			-9 4E+00	-8 4E+00	-7 4E+00	-6 4E+00	

Assumes contamination is exposed at the surface and available for exposure

** 7 months w/ mean temperature > 40 degrees F
Recreational exposure 8 time/month

Summation Recreational Soil Pathways					
L E C R	3 7E-10	3 7E-09	3 7E-08	3 7E-07	
Log L E C R	-9 4349081	-8 43490	-7 43490	-6 43490	

Recreational Summation, All Pathways

	pCi/gr	pCi/gr	pCi/gr	pCi/gr
	0 01	0 1	1	10
L E C R	4 6E-10	4 6E-09	4 6E-08	4 6E-07
Log L E C R	-9 3337841	-8 33378	-7 33378	-6 33378

Recreational Exposure Route Risk Summary

Exposure Route	0 01 pCi/gr Est L E C R	% Contribution
Ingestion of Soluble Species	1 0E-11	2 2%
Ingestion of Suspension Species	2 8E-12	0 6%
Ingestion of Soil	8 3E-11	18 0%
Inhalation of Dust	3 7E-10	79 2%
Summation	4 6E-10	100 0%

Summation of Hybrid-Residential/Recreational Scenario

	pCi/gr	pCi/gr	pCi/gr	pCi/gr
	0 01	0 1	1	10
Residential Facet L E C R	7 0E-10	7 0E-09	7 0E-08	7 0E-07
Residential Facet Log L E C R	-9 1555370	-8 15553	-7 15553	-6 15553
Recreational Facet L E C R	4 6E-10	4 6E-09	4 6E-08	4 6E-07
Recreational Facet Log L E C R	-9.3337841	-8 33378	-7 33378	-6 33378
Hybrid Rec/Res L E C R	1 2E-09	1 2E-08	1 2E-07	1 2E-06
Hybrid Rec/Res Log L E C R	-8 9345493	-7 93454	-6 93454	-5 93454

Exposure Route	0 01 pCi/gr Est L E C R	% Contribution
Residential Facet		
Ingestion of Soluble Species	5 0E-10	42 9%
Ingestion of Suspension Species	1 4E-10	11 7%
Ingestion of Soil	6 4E-11	5 5%
Summation-Residential Facet	7 0E-10	60 1%
Recreational Facet		
Ingestion of Soluble Species	1 0E-11	0 9%
Ingestion of Suspension Species	2 8E-12	0 2%
Ingestion of Soil	8 3E-11	7 2%
Inhalation of Dust	3 7E-10	31 6%
Summation Recreational Facet	4 6E-10	39 9%
Grand Summation	1 16E-09	100 0%

APPENDIX D
DATA SOURCES FOR SITES 200-202

Document	Data Source	Nature of Data
D-1	U S Environmental Protection Agency, "Radioactivity Levels in the Environs of the Rocky Flats Plutonium Plant, Golden, Colorado, 1970," Water Quality Office, Division of Technical Support, Radiological Activities Section, Cincinnati, Ohio, April 1971	Plutonium and other selected radionuclide concentrations in (1) bottom sediment surface grabs and water samples collected in February 1970 from Great Western Reservoir and Walnut Creek, Standley Lake and Woman Creek, Mower Reservoir, and two other nearby reservoirs, and, (2) filtrate from Great Western Reservoir influent water at the Broomfield water treatment plant
D-2	U S Environmental Protection Agency, "Radioactivity Levels in the Environs of the Rocky Flats Plutonium Plant, Colorado, 1970, Part II," Technical Investigations Branch, Surveillance and Analysis Division, Region VIII, 15 December 1973.	Plutonium concentrations in bottom sediment surface grabs and cores, water samples, and biota collected in September 1970 from Great Western Reservoir and Walnut Creek, Standley Lake and Woman Creek, Mower Reservoir, and two other nearby reservoirs (water samples were also analyzed for uranium)
D-3	U S Environmental Protection Agency, "Plutonium Levels in the Sediment of Area Impoundments Environs of the Rocky Flats Plutonium Plant - Colorado," PB-255 572, February 1975	Plutonium, other selected radionuclide, and beryllium concentrations in bottom sediment surface grabs and cores collected in October 1973 from Great Western Reservoir and Standley Lake, and p bottom sediment surface grabs collected in April 1974 from three Colorado Front Range "background" reservoirs
D-4	Dow Chemical, "Survey of Reservoir Sediments," by K K Kunert and G J Werkema, Environmental Sciences and Waste Control Service Report No 317-74-127, 23 August 1974	Presents October 1973 EPA sampling data for Great Western Reservoir and Standley Lake contained in Document D-3, also includes results of duplicate analyses by RFP on approximately one-third of bottom sediment core samples from Great Western Reservoir and Standley Lake

APPENDIX D
DATA SOURCES FOR SITES 200-202
(continued)

Document	Data Source	Nature of Data
D-5	Battelle Pacific Northwest Laboratory, "Radionuclide Concentrations in Reservoirs, Streams and Domestic Waters Near the Rocky Flats Installation," by C W Thomas and D E Robertson, PNL-2919, UC-11, April 1981	Selected radionuclide concentrations in (1) bottom sediment surface grabs and cores collected in May 1974 from Great Western Reservoir and Standley Lake, (2) water samples collected in May 1974 from Great Western Reservoir and Walnut Creek, Standley Lake and Woman Creek, RFP holding ponds, and Broomfield and Westminster tap water, and, (3) filter backwash from Great Western Reservoir influent water at the Broomfield water treatment plant
D-6	U.S Department of Energy, "Time Pattern of Off-Site Plutonium Contamination From Rocky Flats Plant by Lake Sediment Analyses," by E P Hardy and H L Volchok, DOE Environmental Measurements Laboratory, and H D Livingston and J C Burke, Woods Hole Oceanographic Institute, U S DOE Environmental Quarterly Report, July 1978	Plutonium, americium, and cesium-137 concentrations in two sediment cores collected in August 1976 from Standley Lake
D-7	Rockwell International, "Great Western Reservoir Spillway Sediment Sampling Program Phase I Report," by J.D Hurley, Health, Safety, and Environmental Studies, Environmental Sciences, 2 May 1979	Plutonium and americium concentrations in surface grabs and shallow cores collected in March 1979 from sediment on the Great Western Reservoir spillway

APPENDIX D
DATA SOURCES FOR SITES 200-202
(continued)

Document	Data Source	Nature of Data
D-8	Rockwell International, "Great Western Reservoir Spillway Sediment Sampling Program Phase II Report," by J D Hurley, Environmental Sciences, Environmental Studies, ES-376-80-215, 6 August 1980	Plutonium and americium concentrations in cores collected in March 1980 from sediment on the Great Western Reservoir spillway
D-9	Letter from George W Campbell, Acting Director, Health, Safety and Environment, Rockwell International, Rocky Flats Plant, to J R Nicks, Area Manager, DOE-RFAO, subject "Great Western Reservoir Sediment Cores," with attached Great Western Reservoir Sediment Core Data/Graphs presented at 26 March 1985 State Information Exchange Meeting, 85-RF-0457, 14 February 1985	Plutonium concentrations in bottom sediment surface grabs and cores collected in summer 1983 from Great Western Reservoir (includes results from both Rockwell International and City of Broomfield analyses)
D-10	Rockwell International, "Standley Lake Sediment Sample Collection Summary, August, 1984," by G Setlock and M Paricio, Health, Safety and Environment, Environmental Analysis and Control, September 1984	Plutonium concentrations in bottom sediment surface grabs and cores collected in July and August 1984 from Standley Lake
D-11	Colorado Department of Health, "Standley Lake Fish Toxics Monitoring Report," January 1990	Concentrations of plutonium, uranium, cesium-137, selected metals and organics, and pesticides in fish collected in June 1989 from Standley Lake

APPENDIX D
DATA SOURCES FOR SITES 200-202
(continued)

The following documents are published periodically and are available from a number of public information sources Copies of the individual documents are not included in this appendix

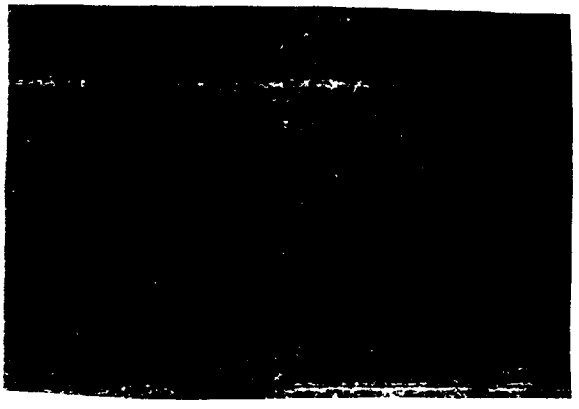
Data Source	Nature of Data
"Rocky Flats Plant Site Environmental Monitoring Report" (published since 1971 by EG&G Rocky Flats, Inc and their predecessors, known prior to 1988 as "Annual Environmental Monitoring Report")	Summarizes results of all environmental investigations and monitoring conducted on and around the RFP during the current year (includes data summarized in monthly environmental monitoring reports--see next entry)
"Rocky Flats Plant Monthly Environmental Monitoring Report" (published monthly since the late 1960s by EG&G Rocky Flats, Inc and their predecessors	Summarizes results of on-site and off-site RFP air and surface water quality monitoring during the current month
"Environmental Surveillance Report on the U S Department of Energy's Rocky Flats Plant" (published monthly since 1970 by the Colorado Department of Health and presented at monthly information exchange meetings)	Summarizes results of off-site RFP air and surface water quality monitoring during the current month

DOCUMENT D-1

"Radioactivity Levels in the Environs of the Rocky Flats Plant, Golden, Colorado, 1970"
(1971)

by

U S Environmental Protection Agency



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Introduction and Background

During the week of February 23, 1970, representatives of the Water Quality Office visited the Rocky Flats Plant of the Atomic Energy Commission (AEC) Located approximately 21 miles northwest of Denver, Colorado, between Golden and Boulder, the facility is operated by the Dow Chemical Company under contract to the AEC The purpose of the visit was to obtain information on liquid radioactive waste management practices at the facility and the environmental surveillance activities in the plant environs Correspondingly, related discussions on the surveillance activities of the State of Colorado were held with personnel of the Department of Health, Division of Air, Occupational, and Radiation Hygiene

The Water Quality Office was represented by Dr. Milton W. Lammering and Mr. Robert C Scott, both of the Radiological Activities Section, Division of Technical Support, Cincinnati, Ohio, and Mr Thomas M Carter, Missouri Basin Region, Kansas City, Missouri In the discussions with personnel of the AEC and Dow Chemical Company, Mr. A. Hazle represented the Colorado Department of Health, Division of Air, Occupational, and Radiation Hygiene

Normal operation of the plant involving the production of plutonium parts for nuclear weapons results in the release of small quantities of plutonium to the environment via the liquid waste treatment system In addition to this controlled and regulated release mode, accidental plutonium releases have occurred on three occasions. a) a major fire in 1957,

b) leakage from a storage field of drums containing plutonium-contaminated oil (some time during 1955 through 1967), and c) a major fire on May 11, 1969. The last incident was the subject of a highly critical report[1] by the subcommittee of the Colorado Committee for Environmental Information. Following the release of the Committee's report, a rash of articles appeared in the local news media on the public health implications of the May 11 fire as well as the general threat to public health and safety posed by the continued operation of the plant. Although WQO involvement was in response to the publicized controversy surrounding the plant, the evaluation by WQO personnel was limited to a review of liquid radwaste management practices and a brief, but intensive, sampling program to determine plutonium levels in the watercourse crossing the plant boundary and nearby lakes and reservoirs. Evaluations of the probabilities of future fires, explosions, and criticality accidents at the plant and the health hazards associated with such incidents are beyond the realm of the vested responsibilities and authority of the Water Quality Office.

A previous Federal inspection of waste disposal practices at the Rocky Flats Plant was conducted on December 18, 1963, by Mr. Keith F. Chrisman, a sanitary engineer in Region VIII, Public Health Service, Department of Health, Education, and Welfare. In recommending no need for remedial action, it was noted that the Colorado State Department of Health had concluded that the facility was not a source of detrimental water pollution. The State's position has not changed in the intervening years.

The following sections of this report pertain to the findings of the February investigation Therefore, discussion of the environmental levels of plutonium is limited to soil, water, and bottom sediment A second report will cover the September 1970 study to determine the plutonium levels in the aquatic biota inhabiting Great Western Reservoir and Standley Lake and the general distribution of plutonium in the bottom sediment of Great Western Reservoir

Liquid Waste Management Practices

All material in the liquid waste effluents from the Rocky Flats Plant ultimately reach Great Western Reservoir, a multiple-purpose reservoir with a maximum storage capacity in excess of 3100 acre-feet. Liquid radioactive wastes, after dilution with treated sanitary sewage, flow through a system of four small retention ponds connected in series. The overflow from this pond system flows down the south fork of Walnut Creek, and subsequently, into Great Western Reservoir (refer to Figure 1). The mouth of Walnut Creek is approximately four miles downstream from the outer plant boundary Except during the spring melt, flow into Great Western Reservoir from Walnut Creek is comprised almost totally of liquid wastes from the plant Great Western Reservoir is the public water supply source for the City of Broomfield.

On-site discharges of liquid radwastes are made at several buildings as indicated by the following list.

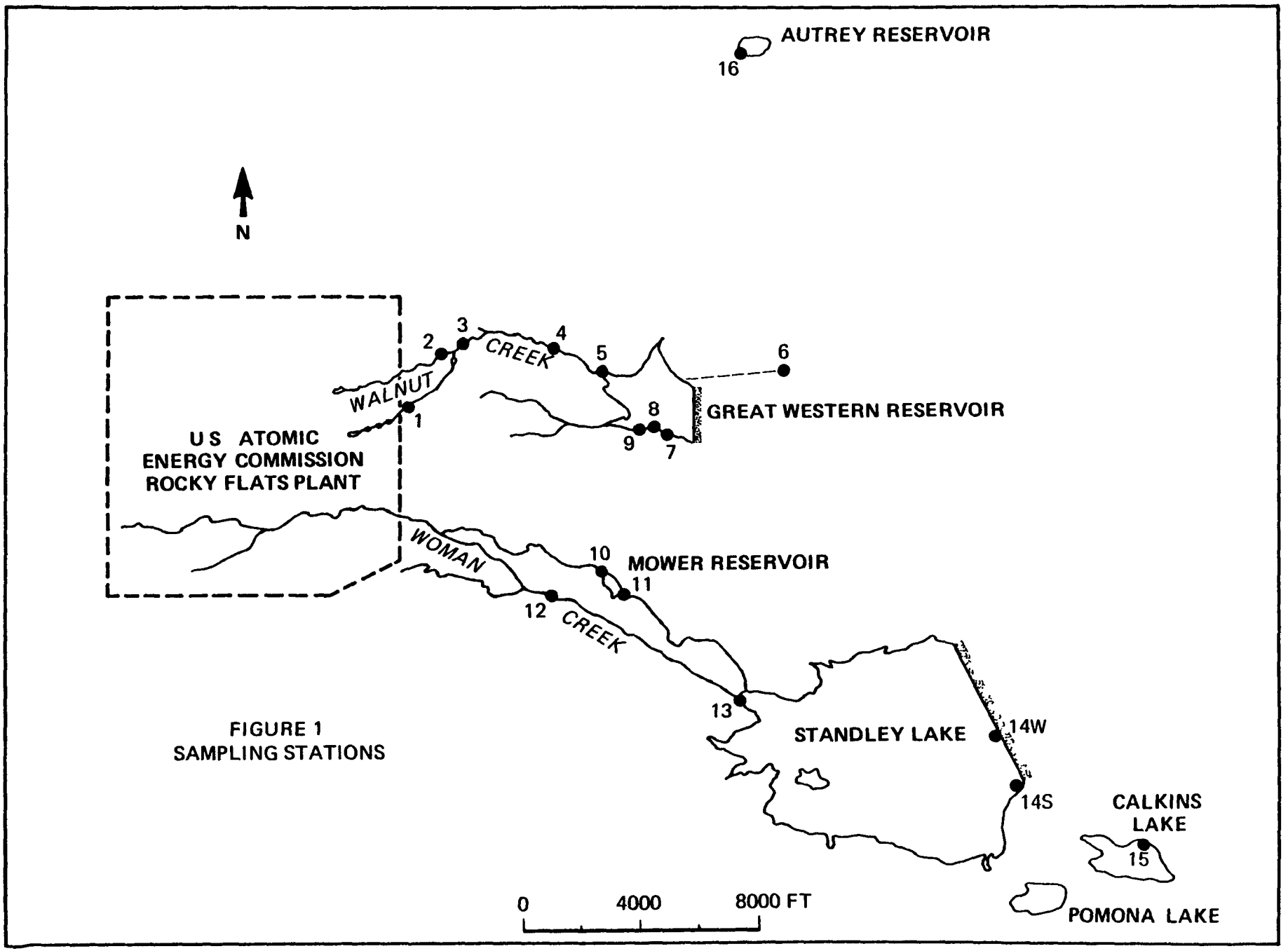


FIGURE 1
SAMPLING STATIONS

Building Identification Number	Major Activity Carried Out in the Building
444	Handling of uranium-contaminated material
771	Plutonium recovery
774	Treatment facility for liquid radwastes
776	Holding tanks for laundry wastes from Building 778 are located in this building
779	Laboratory
881	Handling of uranium-contaminated material
95	Treatment facility for sanitary wastes

The disposal of liquid radwastes from Buildings 444, 771, 776, 779, and 881 is based on the results of chemical analyses of each batch. Normally, wastes from Buildings 771 and 779 are discharged to the drainage ditch carrying wastes to the retention pond system at a point upstream from the sewage treatment plant discharge Liquid wastes from Buildings 444, 776 (laundry wastes), and 881 are mixed with raw sewage and pass through the biological treatment process. If, however, analysis of the waste batch shows that a specific constituent(s) exceeds the concentration limit(s) for discharge without treatment, the batch is transferred to Building 774 for the required treatment For laundry wastes, treatment is required if the following limits are not met.

Plutonium - 3500 dpm/l (approx 1600 pCi/l,*

Nitrate (NO_3^-) - 45 mg/l

Hexavalent chromium - 1 0 mg/l

Concentration limits for treated waste discharges from Building 776, and presumably other buildings, are the same as those cited above for laundry wastes Waste volumes discharged to the drainage ditch and the sewage treatment plant during the last half of 1969 and the corresponding amounts of gross alpha activity are listed in Table I

Two basic processes are available for the treatment of liquid wastes. 1) chemical precipitation and sand filtration, and 2) evaporation with the water vapor vented to the atmosphere As shown on the detailed process flow sheet (Appendix A), flexibility of operation exists within and between the two processes In general, wastes classified as "high radioactivity - low nitrate" wastes are processed by chemical precipitation and filtration, analyzed on a batch basis, and discharged to the drainage ditch upstream from the sewage treatment plant. "High nitrate" wastes are evaporated However, due to the limited capacity of the evaporator, high nitrate wastes are stored initially in a series of three asphalt-lined evaporation ponds for volume reduction Evaporative losses have been sufficiently great to prevent a continuing increase in the volume of stored waste Sludge produced in the

---

* About one-third of the effluent limit for dissolved plutonium-239 as specified in 10CFR20, Appendix B, Table II. Assuming the plutonium is totally in solution is conservative since the corresponding limit for insoluble plutonium is 30,000 pCi/l

Table I

Liquid Radioactive Waste Disposal - July through December 1969

Source	Volume (gallons)	Gross Alpha Radioactivity (curies)
To drainage ditch from:		
Building 771	23,000	1.3×10^{-4}
Building 774	1,117,600	1.4×10^{-3}
Building 779	91,400	9.1×10^{-5}
To sewage treatment plant from:		
Building 444	146,500	$1\ 9 \times 10^{-3}$
Building 776	1,137,200	5.4×10^{-3}
Building 881	261,400	2.4×10^{-3}

decontamination of liquid radwastes is drummed for off-site burial at the National Reactor Testing Station (Idaho)

The sewage treatment plant is an extended aeration facility with a chlorinated effluent Although the purpose of the plant is the treatment of non-radioactive sanitary wastes, some degree of decontamination of the radwastes from Buildings 444, 776, and 881 is also achieved by the treatment process The uranium-contaminated sludge from the digester is buried in an on-site landfill unless established radioactivity limits are exceeded In the latter case, the sludge is drummed for shipment to the National Reactor Testing Station The plant effluent also has a dilution effect on wastes discharged to the drainage ditch from Buildings 771, 774, and 779.

Although the system of ponds receiving the combined plant effluent was designed to provide retention of liquid wastes before entry into the unrestricted environment, the ponds also function as a series of oxidation ponds providing additional treatment of the organic-bearing wastes Similarly, the luxurious algal growths undoubtedly produce additional decontamination of the plant wastes. However, this reduction in the amount of radioactivity released to the environment will not be realized on a long-term basis if the ponds are scoured during periods of high run-off The effluent from the pond system is sampled proportional to flow and composited for analysis (gross alpha, nitrate, phosphate, fluoride, and hexavalent chromium) Gross alpha activity in the effluent is usually on the order of 15 pCi/l which by inference indicates that plutonium releases are

well below the operational limit of 1600 pCi/l.[2] Phosphate concentration data for 1969 were as follows:

Maximum - 38 mg/l as $PO_4^{\equiv}$

Minimum - 0.4 mg/l

Average - 8.9 mg/l

Due to decontamination in the sewage treatment plant and retention ponds, the net release of gross alpha activity to Walnut Creek during the last half of 1969 should have been less than the total of 11.3×10^{-3} curies shown in Table I.

Environmental Surveillance

Monitoring of environmental radioactivity levels in the environs of the Rocky Flats Plant is conducted routinely by personnel of the Dow Chemical Company. Based on the semi-annual monitoring reports published in the U. S. Public Health Service periodical, "Radiological Health Data and Reports," the operational details of the surveillance program are the following:

Type of Sample	Description
Air	Continuous air samples are collected at Coal Creek Canyon, Marshall, Boulder, LaFayette, Broomfield, Wagner School, Golden, Denver, and Westminster Analyses of monthly composite samples are reported as a single average concentration for all stations.
Water	Except during winter months, monthly samples are collected from Baseline Reservoir, Great Western Reservoir, Standley Lake, and Ralston Reservoir.
Vegetation	Semi-annual collection, i e , during one month of each six month reporting period. Samples are analyzed in accordance with two collection zones, less than four miles from the plant and four to eighteen miles from the plant

[illegible] soil samples [illegible] added to the surveillance program [illegible] fire. Samples are analyzed for gross alpha activity. This includes naturally-occurring radionuclides (uranium, thorium, radium, etc.) as well as any plutonium that might be present as a result of plant operations and/or atmospheric fallout.

The results of the monitoring program for 1969 and the first half of 1970 are shown in Table II. These data do not show any significant increases in gross alpha levels above natural background in the media sampled as the result of plant operations (including accidental releases). Since there is no information to indicate otherwise, it is assumed that the gross alpha results for water samples are representative of total activity (suspended plus dissolved).

The State of Colorado Department of Health routinely samples Walnut Creek at Indiana Street (just upstream from the mouth) on a weekly basis for gross alpha activity analysis. If the gross alpha activity is unusually high a portion of the sample is sent to the Public Health Service Southwest Radiological Health Laboratory for plutonium analysis.

In addition to the routine surveillance programs carried out by Dow Chemical Company and the State Health Department, intensified monitoring was undertaken following the May 11 fire. During May and June 1969 Dow Chemical Company reported the collection and analysis of 52 additional water samples from the routinely sampled reservoirs.[3] The Denver Post in an editorial dated February 12, 1970, reported that the State Health Department collected 670 air samples and 94 water samples in the vicinity of the plant in the

Table II

Gross Alpha Activities in the Environs of the Rocky Flats Plant

Composite Air Samples ($pCi/M^3 \times 10^{-2}$)

1968	January	0.3	1968	July	0.5	1969	January	0.5
	February	2.2		August	0.5		February	0.4
	March	0.5		September	0.6		March	0.2
	April	0.5		October	0.7		April	0.3
	May	0.3		November	0.4		May	0.3
	June	0.7		December	0.7		June	0.3

Grab Water Samples (pCi/l)

	Jan.-June 1968	July-Dec. 1968	Jan.-June 1969
Great Western Reservoir	2.3	1.4	1.4
Standley Reservoir	1.3	1.5	1.5
Baseline Reservoir (7 miles north of site)	1.2	0.9	0.9
Ralston Reservoir	4.2	2.8	2.8

Vegetation (pCi/kg)

October 1967	
< 3 miles	120 (21)*
3-18 miles	118 (40)
October 1968	
< 4 miles	90 (62)
4-18 miles	96 (44)
May 1969	
< 4 miles	84 (39)
4-18 miles	77 (20)

* Number in parentheses denotes number of analyses

Source References 3, 4, and 5

time period extending from one day after the fire through October 1969. The State Health Department also conducted an extensive soil and bottom sediment sampling program in February 1970. Soil samples were collected in the area around the plant up to a maximum radial distance of six miles. Bottom sediment samples were collected from Walnut Creek, Woman Creek, Great Western Reservoir, Mower Reservoir, Standley Lake, and Ralston Reservoir. Analyses for strontium-89 and 90 and plutonium-239 were performed by the Public Health Service Southwest Radiological Health Laboratory (Appendix B).

Following the May 11 fire, members of the Colorado Committee for Environmental Information also undertook a limited program to determine plutonium levels in Colorado eastern slope soils and at locations in the vicinity of the Rocky Flats Plant. In addition to the soil samples, water and bottom sediment samples were collected from Walnut Creek, Great Western Reservoir, Calkins Lake, Ralston Reservoir, and three more distant lakes: Boulder Reservoir (northeast of Boulder), Dodd's Lake (northeast of Boulder), and Boyd Lake (Loveland, Colorado). Based on the results obtained for the soil samples, it was concluded "that curies to tens of curies of plutonium from the Rocky Flats Plant have been deposited in off-site areas." This is in contrast to the estimate of 0.3 curie by the State of Colorado Department of Health (Appendix B).

Water Quality Office Study

Sampling Procedures

Environmental samples were collected on February 25 and 26, 1970 by Water Quality personnel with assistance from Mr. A. Hazle, Colorado Department of

Health The types of samples consisted of water samples, bottom sediment samples, and filter sand and clarifier underflow samples from the Broomfield Water Treatment Plant

Sampling station locations for water and bottom sediment samples are presented in Table III and Figure 1. Bottom sediment samples were collected by scraping the bottom area below the water line with a hand trowel By using this procedure, each sediment sample was representative of the bottom most readily available for physical and chemical reactions with dissolved constituents in the water and recently deposited material. Grab samples of water were collected in one gallon plastic containers, 2 to 5 gallons per sample

Soil samples (top 1/4" - 1/8" of soil) were collected with a hand trowel at three locations.

1 Ungrazed area near the southeast corner of Great Western Reservoir, west of the service road.
2 Approximately 50 feet southeast of the road culvert conveying Woman Creek under Indiana Street Area has been grazed in the past.
3 North side of Calkins Lake, about 300 feet east of the water intake station (grazed field)

The sampling site near Great Western Reservoir was in the general area of the location at which the Colorado Committee for Environmental Information observed the maximum plutonium-239 concentration in soil

Filter sand samples, before and after backwashing, and a sample of the clarifier underflow were collected at the Broomfield Water Treatment Plant The filter sand samples were collected by scraping the surface of the sand bed with a hand trowel. The sample collected at the termination of the filter run was a mixture of "scum" and filter sand (white), the scum representing alum floc carried over from the clarifier. Clarifier underflow, a heavy slurry, was the product of alum coagulation of Great Western Reservoir water Due to maintenance work on one of the two treatment circuits, the 5 MGD plant was hydraulically overloaded at the time of sample collection. Raw water chemical dosages were 50 mg/l alum, 20 mg/l soda ash, 1.0 mg/l activated carbon, and 0 5 mg/l Palmer coagulant (product of the Calgon Corporation).[6]

Analytical Procedures

The analytical procedures for determining gross alpha radioactivity, total alpha radium, uranium, plutonium, strontium-89 and 90, and tritium concentrations in the various environmental samples are described in detail in Appendix C Pretreatment of water samples consisted of filtration through a membrane filter of 0.45 micron porosity Sediment and soil samples were dried at 103°C and ground to pass a No. 100 mesh sieve before specific analyses were initiated.

Since the analytical procedure for plutonium determines "total" plutonium, the individual results represent the contributions of plutonium-238 and 239, not plutonium-239 alone By virtue of their widespread occurrence in the atmosphere, both isotopes of plutonium were probably present in

Table III

Sampling Stations

Station Number	Description (Date of Collection)	Type
1	South fork of Walnut Creek at site boundary (2/25/70)	Water, Bottom Sediment
2	Middle fork of Walnut Creek, 50 feet upstream from confluence with north fork (2/25/70)	Water, Bottom Sediment
3	Main stem of Walnut Creek; 50 feet downstream from confluence of south fork with middle and north forks (2/25/70)	Bottom Sediment
4	Walnut Creek at Indiana Street (2/25/70) (a) East side of culvert (b) West side of culvert at edge of small pond	 Water Bottom Sediment
5	Great Western Reservoir at mouth of Walnut Creek (2/25/70)	Bottom Sediment
6	Great Western Reservoir, east end - raw water sample collected at Broomfield Water Treatment Plant (2/25/70)	Water
7	Great Western Reservoir; south shore - composite sample collected along approximately one-half mile of shoreline extending from the dam (2/25/70)	Bottom Sediment
8	Great Western Reservoir, south shore - composite sample collected along a 25 foot strip in 2 to 5 inches of water (2/26/70)	Bottom Sediment
9	Great Western Reservoir, south shore - discrete sample collected above water line from wave-deposited (or reworked) sediments (2/26/70)	Bottom Sediment
10	Mower Reservoir at mouth of diversion ditch, west end (2/26/70)	Bottom Sediment

(continued)

Table III (continued)

Sampling Stations

Station Number	Description (Date of Collection)	Type
11	Mower Reservoir, east end at dam (2/25/70)	Water, Bottom Sediment
12	Woman Creek at Indiana Street (2/26/70) (a) Small pond east of the road culvert (b) Channel downstream from pond	 Water Bottom Sediment
13	Standley Lake near mouth of Woman Creek (2/26/70)	Bottom Sediment
14	Standley Lake; east end (2/26/70) (a) Center of dam near pumping station (b) Southwest of dam along a 25 foot edge of shoreline in zone of heavy wave action	 Water Bottom Sediment
15	Calkins Lake, north side (2/26/70)	Water, Bottom Sediment
16	Autrey Reservoir (approximately 4 miles northeast of the plant, Boulder County) (2/25/70)	Water, Bottom Sediment

the samples collected in the environs of the Rocky Flats Plant However, the bulk of the plutonium in each case was probably attributable to plutonium-239 This conclusion is based on the plutonium monitoring of airborne particulates and precipitation by the U. S. Public Health Service. During 1969 the data for the Denver sampling station showed plutonium-239 concentrations to be several times higher than the corresponding plutonium-238 concentrations. Although the ability to differentiate between plutonium-238 and 239 is of interest from the standpoint of analytical precision, it is of academic importance in respect to evaluating the environmental impact of plutonium-239 emissions from the Rocky Flats Plant Total plutonium is an adequate parameter for such an evaluation since the effects of plant emissions are based on increases above baseline values (plutonium attributable to atmospheric fallout).

Results

Physical and radiological data for the water samples collected during the February 1970 study are tabulated in Tables IV and V. The presence of tritium (H-3), strontium-89 and 90, and radium (total alpha) in the samples is attributable to natural sources and/or atmospheric fallout from nuclear weapons tests, not waste releases (scheduled or accidental) from the Rocky Flats Plant. The average dissolved concentrations of these radionuclides were 1340 pCi/l of tritium, < 0.1 pCi/l of strontium-89, 1 2 pCi/l of strontium-90, and < 0 1 pCi/l of total alpha radium

Assuming the accidental releases of plutonium from the Rocky Flats Plant have not caused measurable increases in the levels of dissolved

Table IV

Solids Concentrations in Water Samples

Station	Solids Concentration (mg/l) Suspended	Dissolved
Walnut Creek.		
South fork at site boundary (No 1)	13	150
Middle fork (No 2)	4	220
Indiana Street (No. 4)	12	250
Great Western Reservoir (No 6)	4	130
Mower Reservoir (No. 11)	17	110
Woman Creek (No. 12)	< 1	150
Standley Lake (No 14)	5	120
Calkins Lake (No. 15)	16	80
Autrey Reservoir (No 16)	13	220

Table V

Dissolved Radioactivity in Water Samples

Station	Dissolved Radioactivity (pCi/l)[a] Gross Alpha	Tritium	Sr-89	Sr-90	Total Alpha Radium	Uranium	Plutonium-239
Walnut Creek. South fork at site boundary (No. 1)	N D.	N.D.	0	0 6	0 1	7 9	0.04
Middle fork (No. 2)	0 9	N D.	0.1	0 7	< 0.1	2 7	0 02
Indiana Street (No 4)	0 6	N D.	0.1	0.6	< 0 1	4.8	0 05
Great Western Reservoir (No 6)	0 8	1340	0	1 4	0 1	2 6	0 03
Mower Reservoir (No 11)	0 8	1050	0	1 8	0.1	1 1	< 0 02
Woman Creek (No 12)	0.9	N.D.	0 5	0 4	< 0.1	2 2	< 0 02
Standley Lake (No 14)	0.5	1390	0	0 6	< 0 1	2 4	< 0 02
Calkins Lake (No 15)	0 5	1550	0	2.2	0.2	2 7	0.03
Autrey Reservoir (No. 16)	0.8	1390	0	2.1	< 0 1	0 5	< 0 02

(a) Uranium in µg/l

N.D - Not determined

[illegible] [illegible] Reservoir, [illegible] [illegible] [illegible]

[illegible]

[illegible]

[illegible]

[illegible] respectively. Similarly, these [illegible] were the only locations at which the dissolved uranium concentration exceeded [illegible] average area background concentration of [illegible] [illegible] of raw water [illegible] Great Western Reservoir ([illegible]), did not indicate any increased level of uranium and/or plutonium [illegible] as the result of liquid waste discharges to Walnut Creek.

For comparative purposes the plutonium-239 [illegible] reported by the Colorado Committee for Environmental Information[4] are summarized below. It is assumed that the samples were collected during [illegible] 1970.

Location	Plutonium-239 (pCi/l)
Walnut Creek - Roadside pond at Indiana Street	0.1
Great Western Reservoir	0.10
Ralston Reservoir	0.01
Collins Lake	0.01

These data agree favorably with the corresponding results from the present study. The substantially higher concentration in Walnut Creek is not unusual [illegible] considering probable differences in flow conditions [illegible]

and the batch nature of liquid waste discharges. What does appear to be a significant difference is the concentration reported for Great Western Reservoir which would be indicative of measurable contamination in the reservoir as the result of plant wastes However, the discussion of the results in their report indicates that this station was actually located in or near the mouth of Walnut Creek:

> " The highest Pu^{239} concentrations observed are those for Great Western Reservoir and the small roadside pond, both on Walnut Creek .. "

Thus, this particular sample was apparently not representative of general water quality in Great Western Reservoir.

The radioactivity data for bottom sediment samples are presented in Table VI. Average concentrations of strontium-89, strontium-90, and total alpha radium in all sediment samples were < 0 5, 0.1, and 4 9 pCi per gram dry weight, respectively. For all stations, except those on Walnut Creek, the uranium concentrations ranged from 0.4 to 2 8 µg per gram dry weight, averaging 1 0 µg/gram. Considering these values and the result for the middle fork sample, no significant accumulation attributable to the discharge of uranium-bearing liquid wastes was observed in the Walnut Creek samples Excluding the station on the middle fork, the average uranium concentration for Walnut Creek sediments was 1 5 µg/gram The average concentration for plutonium-239 at baseline locations (Autrey Reservoir, Standley Lake, and Calkins Lake) was 0 05 pCi per gram dry weight This baseline concentration is comparable to the concentrations reported by the Colorado Committee for Environmental Information[1] and the State of Colorado (Appendix B) for

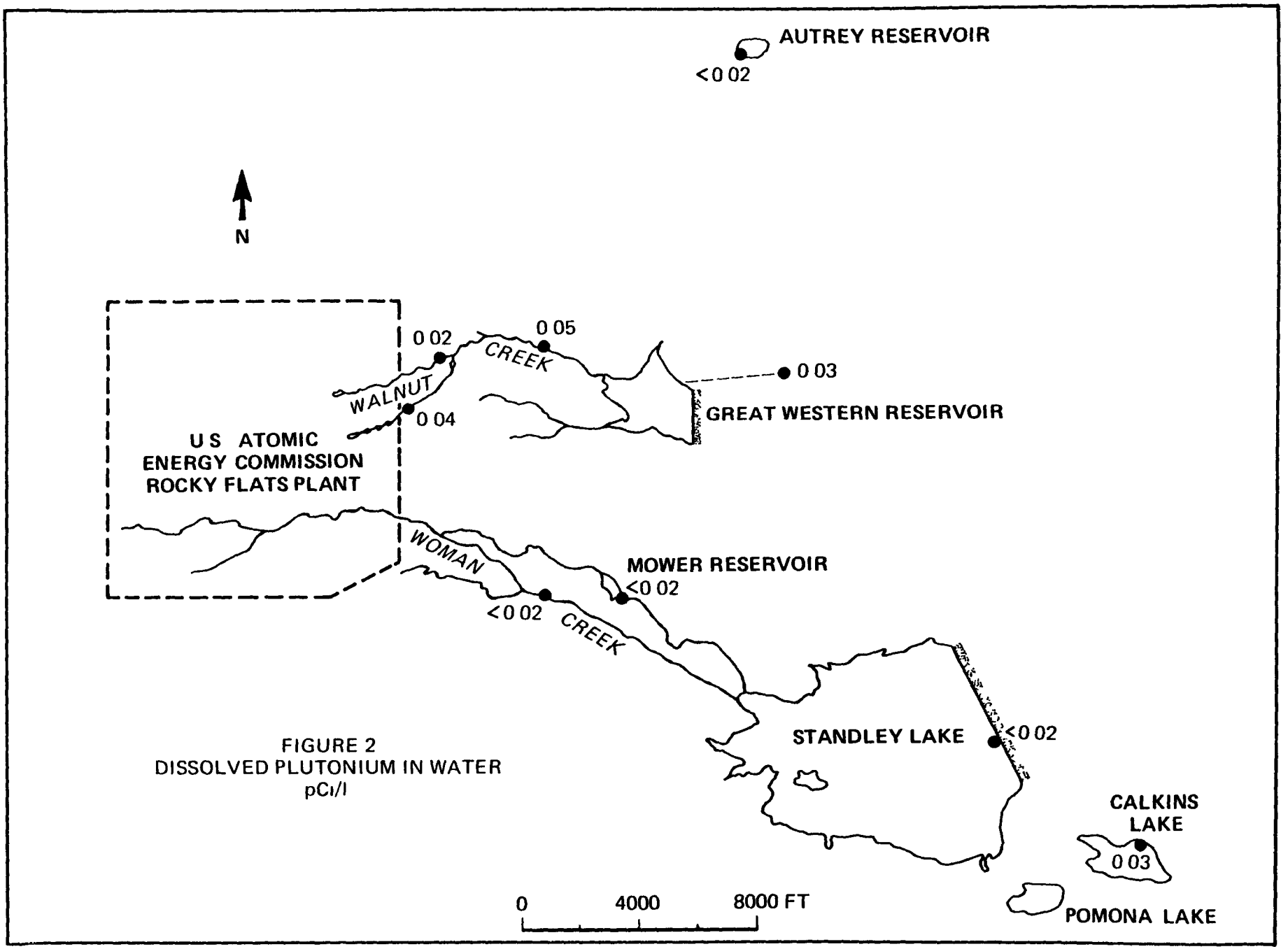


FIGURE 2
DISSOLVED PLUTONIUM IN WATER
pCi/l

[illegible] range of 0 01 [illegible]

[illegible] liquid [illegible] as shown in Table [illegible] and Figure [illegible], plutonium concentrations [illegible] ranged from a maximum 3 5 pCi/gram just below the plant boundary [illegible] pCi/gram [illegible] the lower reach of the main [illegible] Creek [illegible]). In comparison to the observed level of [illegible] baseline), similar results obtained by the State of Colorado [illegible] substantially higher level of contamination. These [illegible] corresponding to the collection date of February 1[illegible], 1970, were as follows.

Location	Plutonium-2[illegible] (pCi/gram dry weight)
Upper south Walnut Creek	[illegible]1
Walnut Creek	
Pond, Walnut Creek at Indiana Street	[illegible]5

Since flushing of the creek by heavy runoff did not [illegible] the [illegible] between the collection dates, the only reasonable explanations for the apparently different sets of findings are differences in the [illegible] characteristics of the sampling locations (pool versus riffle or [illegible] thereof) and sampling techniques (thickness of the scraped layer, heterogeneity of sample composition, etc). For example, considerable variation would be expected for samples collected from the pond at Indiana Street

Table VI

Radioactivity in Bottom Sediment Samples

Station	Radioactivity Concentration (pCi/gram dry weight)[a]				
	Gross Alpha	Strontium-90	Total Alpha Radium	Uranium	Plutonium-239
Walnut Creek.					
South fork at site boundary (No. 1)	18	0.1	3 4	1 1	3 51
Middle fork (No 2)	10	0.1	5.4	2.3	0 50
Main stem, below confluence with middle fork (No. 3)	17	0	2.8	1.0	3 41
Indiana Street (No. 4)	14	0.1	4.1	2.1	0.92
At the mouth (No 5)	13	0.3	6.3	1 9	1 75
Great Western Reservoir.					
South shore near dam (composite)(No. 7)	7	0 2	5.4	1 3	0.10
South shore (composite) (No 8)	12	0	6.3	0 4	0 11
South shore (discrete sample)(No. 9)	12	0 2	6.6	2 8	0.13
Mower Reservoir:					
West end (No. 10)	11	0	4.3	0.5	0.10
Last end (No 11)	13	0 1	3.3	0 4	0 09
Woman Creek (No 12)	9	0	4.8	1 5	0 23

(continued)

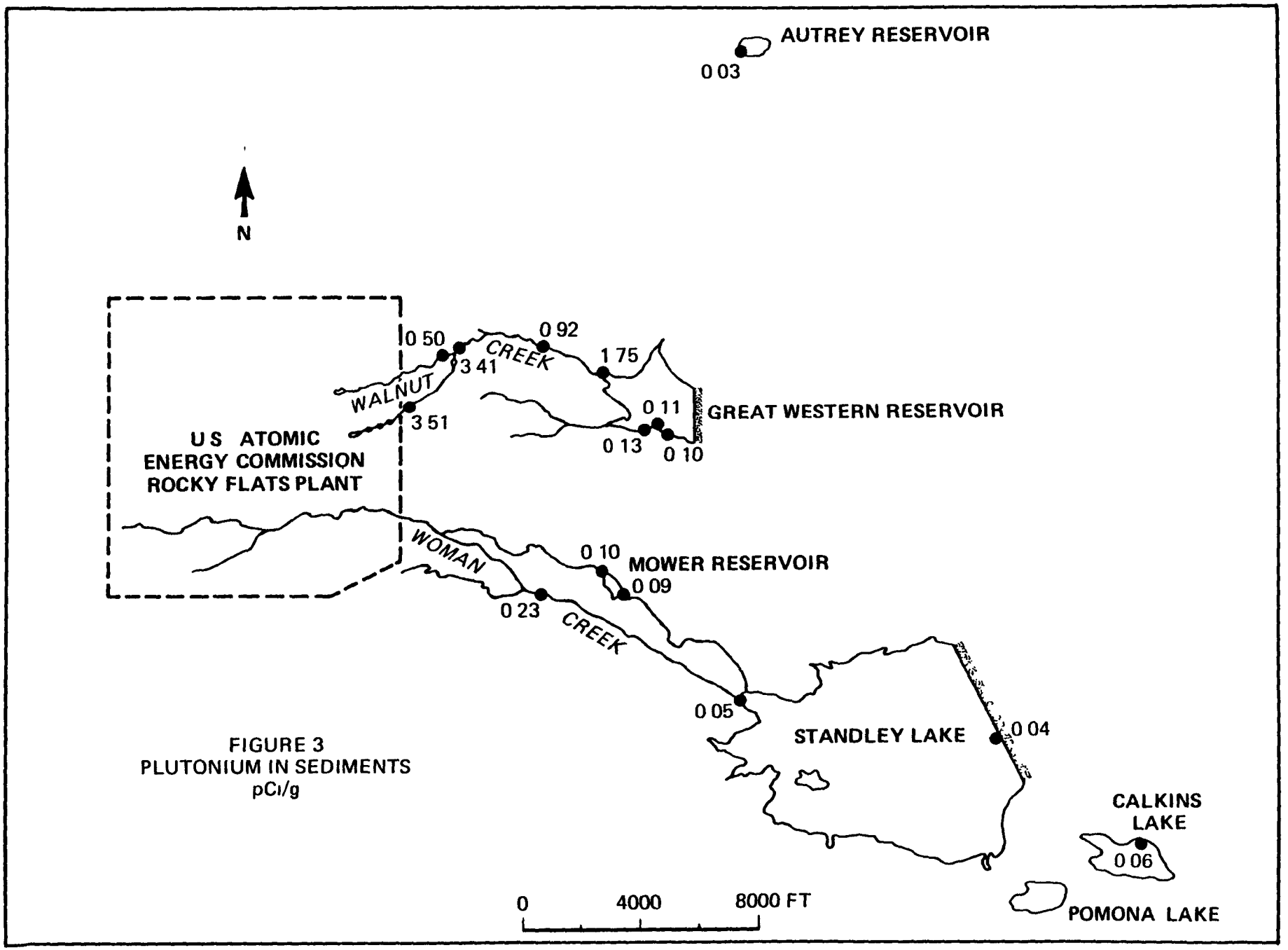


FIGURE 3
PLUTONIUM IN SEDIMENTS
pCi/g

Table VI (continued)

Radioactivity in Bottom Sediment Samples

Station	Radioactivity Concentration (pCi/gram dry weight)[a]				
	Gross Alpha	Strontium-90	Total Alpha Radium	Uranium	Plutonium-239
Standley Lake					
Near mouth of Woman Creek (No 13)	10	0.2	12 5	0 6	0 05
East end (No 14)	8	0	0 7	0.6	0.04
Calkins Lake (No 15)	7	0	4 3	0.7	0 06
Autrey Reservoir (No 16)	8	0.2	3.2	0 7	0 03

(a) Uranium in μg/gram

Strontium-89 less than 0 5 pCi/gram in each case

depending on whether the samples are collected near the head end of the pond, the center, or just below the waterline along the periphery of the pond The contamination observed in sediment from the middle fork of Walnut Creek and Woman Creek (at Indiana Street) was probably caused by wind transport and/or surface runoff of plutonium-contaminated soil The State of Colorado also observed contamination in Woman Creek - 1 0 pCi/gram for a sample collected on February 18, 1970

Although certainly not conclusive, the sediment samples from Mower Reservoir and Great Western Reservoir indicated measurable, albeit slight, accumulation of plutonium as the result of accidental airborne releases from the plant The discharge of plutonium-bearing liquid wastes was not considered a causative source since the samples from Great Western Reservoir were collected at locations wherein the ultimate deposition of sediment from Walnut Creek would be most unlikely. Actually, these sediment samples should be considered representative only of shallow, shoreline conditions and not the general bottom condition in the respective reservoirs. Assuming the bottom materials in these shallow areas were similar to nearby topsoils as regards plutonium content, the suggested possibility of accumulation above baseline values in the shoreline sediments is not completely implausible. Both reservoirs are within sectors characterized by "elevated" levels of plutonium in soil (Appendix B)

The clarifier underflow sample from the Broomfield Water Treatment Plant showed that the treatment process produced a finished water of lower uranium and plutonium concentrations than the raw water On a dry weight

[illegible] sludge [illegible] the maximum [illegible] [illegible] samples analyzed [illegible] plutonium concentrations [illegible] [illegible] de- [illegible] tion that observed for [illegible] brook sediment samples (Table III). [illegible] of the flow [illegible] the sediment filter was [illegible] by the [illegible] and plutonium content of the filter and samples collected before and after [illegible]

Plutonium levels observed in the three soil samples are summarized in Table III, and are consistent with similar findings of the State of Colorado and the Colorado Committee for Environmental Information.

Spearman rank-order correlations were performed between the gross alpha and uranium, total alpha radium, and plutonium results, respectively, for sediment and soil samples. Interestingly, there was no correlation between gross alpha and uranium or gross alpha and total radium, but a significant correlation between gross alpha and plutonium results at the 1% confidence level. Despite this relationship, gross alpha measurements alone are not adequate for assessing the environmental impact of plutonium released (accidental or scheduled) from the plant. Although the gross alpha analysis is responsive to substantial increases in plutonium levels, it lacks sufficient precision for detecting the small subtle changes that may occur in the environs of the Rocky Flats Plant.

Table VII

Broomfield Water Treatment Plant Samples

Sample Description	Radioactivity Concentration (pCi/gram dry weight)[a]				
	Gross Alpha	Strontium-90	Total Alpha Radium	Uranium	Plutonium-239
Clarifier underflow (alum sludge)	34	1.2	3 1	57 5	1 42
Filter sand:					
Before backwash	12	0 3	3.0	20	0 16
After backwash	4	0	0 3	0.2	0 04

(a) Uranium in µg/gram

Table VIII

Radioactivity in Soil Samples

Location	Radioactivity Concentration (pCi/gram dry weight)[a]					
	Gross Alpha	Strontium-89	Strontium-90	Total Alpha Radium	Uranium	Plutonium-239
Ungrazed area near the southeast corner of Great Western Reservoir.(NE 1/4 Sec 7, T 2S.,R 69W.)	12	< 0.5	0 6	4 5	1.7	0 42
North side of Calkins Lake, ungrazed field east of water intake station. (NW 1/4 Sec 26, T.2S., R 69W)	7	< 0 5	0.4	4 0	2 8	0.07
Grazed area just to the southeast of the road culvert conveying Woman Creek under Indiana Street (NW 1/4 Sec. 18, T 2S., R 69W)	16	< 0.5	1 6	5.4	1 0	2 42

(a) Uranium in µg/gram

Discussion

Surface contamination of land surfaces in the vicinity of the Rocky Flats Plant has occurred as the result of uncontrolled releases of plutonium. The special soil sampling program conducted by the State of Colorado in February 1970 showed plutonium concentrations in excess of that attributable to global fallout at radial distances up to three miles from the plant boundary The two sectors (refer to Appendix B) immediately adjacent to the plant showed the maximum topsoil concentrations of plutonium-239, 2.5 and 11 pCi per gram dry weight It was the State's conclusion that the primary source of contamination was the "incident" involving the leakage of oil and not the May 11, 1969, fire In contrast, the report of the Colorado Committee for Environmental Information strongly suggested the May 11 fire as the primary causative factor. As far as the public health implications of the land contamination are concerned, the source, whether it be the incident involving the fire or the oil leakage, is not really revelant

It is extremely difficult to attempt to relate plutonium concentrations in unconsolidated topsoil to possible or potential levels of human exposure Deposited in-place, there is no significant health risk External exposure will not occur because of the very limited range of the emitted alpha radiation Similarly, transfer through the food chain (for example, soil to vegetation to wild game or grazing stock) will be of no consequence since plutonium is absorbed by plants growing on contaminated soil to only an infinitesimal degree [7] However, resuspension and wind transport of contaminated particulates - apparently a likely condition for the Rocky Flats area - may lead to inhalation and resultant radiation dose For discussion of

[illegible] and the public [illegible] processes, [illegible] reader is referred to the report of Colorado's analysis (Appendix) and the report of the Colorado Committee for Environmental Information.

The discharge of liquid radioactive wastes has observed to have only a minor effect on dissolved radioactivity concentrations in Walnut Creek, at least during the two-day sampling period. The dissolved concentrations of uranium and plutonium were just slightly in excess of baseline values and, in each case, several orders of magnitude less than the corresponding effluent concentration specified in AEC regulation 10CFR20, and the limiting concentration in water for the general public, as recommended by the National Committee on Radiation Protection and the International Commission on Radiological Protection (Table IX). Unfortunately, the degree to which the specific grab sample results are representative of average or long-term conditions can only be determined by additional monitoring. The effluent to the south fork of Walnut Creek has been continuously sampled by plant personnel and the State of Colorado has been monitoring Walnutcreek at India a Street. The analysis of these samples usually involves only total gross alpha determinations, the results of which are not directly comparable with dissolved radioactivity data. However, the effluent concentration of total gross alpha activity stated to be typical, 15 pCi/l, indicates that specific grab samples for the levels of dissolved uranium and plutonium may usually be representative of average water quality conditions in the creek.

The most demonstrable effect of liquid radioactive waste discharges was the accumulation of plutonium in bottom sediments throughout the entire

Table IX

Limiting Concentrations for Plutonium-239 and Uranium

Agency	Radionuclide	Dissolved Concentration Limit	Applicability
Atomic Energy Commission	Plutonium-239	5000 pCi/l	Effluent at point of entry into the unrestricted area
	Uranium-238	120 mg/l	
National Committee on Radiation Protection	Plutonium-239	1700 pCi/l[(a)]	Exposure of the general public
International Commission on Radiological Protection	Uranium-238	40 mg/l (NCRP)[(a)]	Exposure of the general public
		600 µg/l (ICRP)[(a)]	

(a) 1/30th of the maximum permissible concentration for continuous occupational exposure (168-hour week).

length of Walnut Creek. Representing accumulation and deposition over an undetermined period of time, the February 1970 sediment samples contained plutonium in concentrations as high as 3 5 pCi/gram (State of Colorado data showed a maximum of about 20 pCi/gram) Such accumulation occurs by two processes: 1) deposition of plutonium associated with suspended material in the effluent, and 2) transfer of plutonium from the dissolved (ionic) state by chemical precipitation and/or adsorption. From the standpoint of environmental significance as regards human exposure, plutonium deposited in Walnut Creek is of no consequence. However, these contaminated sediments are periodically flushed out of the creek and deposited in Great Western Reservoir wherein there exists availability for incorporation and accumulation in the aquatic web. The limited available information on the movement of plutonium in the environment indicates that biological accumulation as well as dissolution of plutonium from the sediment will be negligible. Nonetheless, the previously mentioned study of September 1970 was conducted to ensure that these predictions are indeed valid.

In contrast to the situation in the south fork and main stem of Walnut Creek, the sources of elevated plutonium concentrations in samples from the middle fork of Walnut Creek, Woman Creek, and shallow shoreline areas of Great Western Reservoir and Mower Reservoir were considered to be air transport and surface runoff of plutonium-contaminated soil. As noted in the preceding paragraph, the plutonium deposited in these areas is probably biologically and chemically inert

Increased levels of dissolved radioactivity attributable to plant releases were not observed in any of the lakes and reservoirs sampled This finding is generally supported by the long-term monitoring data compiled by plant personnel for several reservoirs in the plant environs, including Great Western Reservoir and Standley Lake However, since the plant monitoring program is limited to total gross alpha determinations, detection of small increases in plutonium concentrations, such as those observed in Walnut Creek, would not be expected It is also interesting to note that the concentrations of dissolved uranium in the grab water samples from Great Western Reservoir and Standley Lake almost totally account for the corresponding reported levels of total gross alpna concertrations The radiation dose associated with the utilization of Great Western Peservoir, Standley Lake, and Calkins Lake as sources of public water supply is negligible Without taking credit for possible concentration reductions achieved by water treatment, the dose received by members of each population group served is less than one one-hundred-thousandth (10^{-5}) of the dose limit for individuals

The apparent effectiveness of the Broomfield water treatment process for reducing uranium and plutonium concentrations - raw versus finished water - was indicated by the radioactivity results for the sample of settled alum sludge. On a dry weight basis, the plutonium and uranium concentrations in the sludge were comparable to the plutonium concentrations and about 40X the uranium concentrations in Walnut Creek sediment Disposal of the sludge is to a small retention pond adjacent to the water treatment plant

Conclusions

Monitoring data do not indicate any public health hazard due to the routine discharge of liquid radioactive wastes to Walnut Creek as there is no measurable degradation of plankton [illegible] in the natural water quality of Great Western Reservoir, the source of public supply for the City of Broomfield. This reflects the general adequacy of the liquid waste management program carried on at the Rocky Flats Plant. In this respect, additional abatement requirements are not indicated at this time.

Recommendations

In order to obtain a more comprehensive documentation of the radioactivity discharged to the environment via the liquid radioactive waste treatment and disposal system and the ultimate distribution thereafter, the Water Quality Office has the following recommendations:

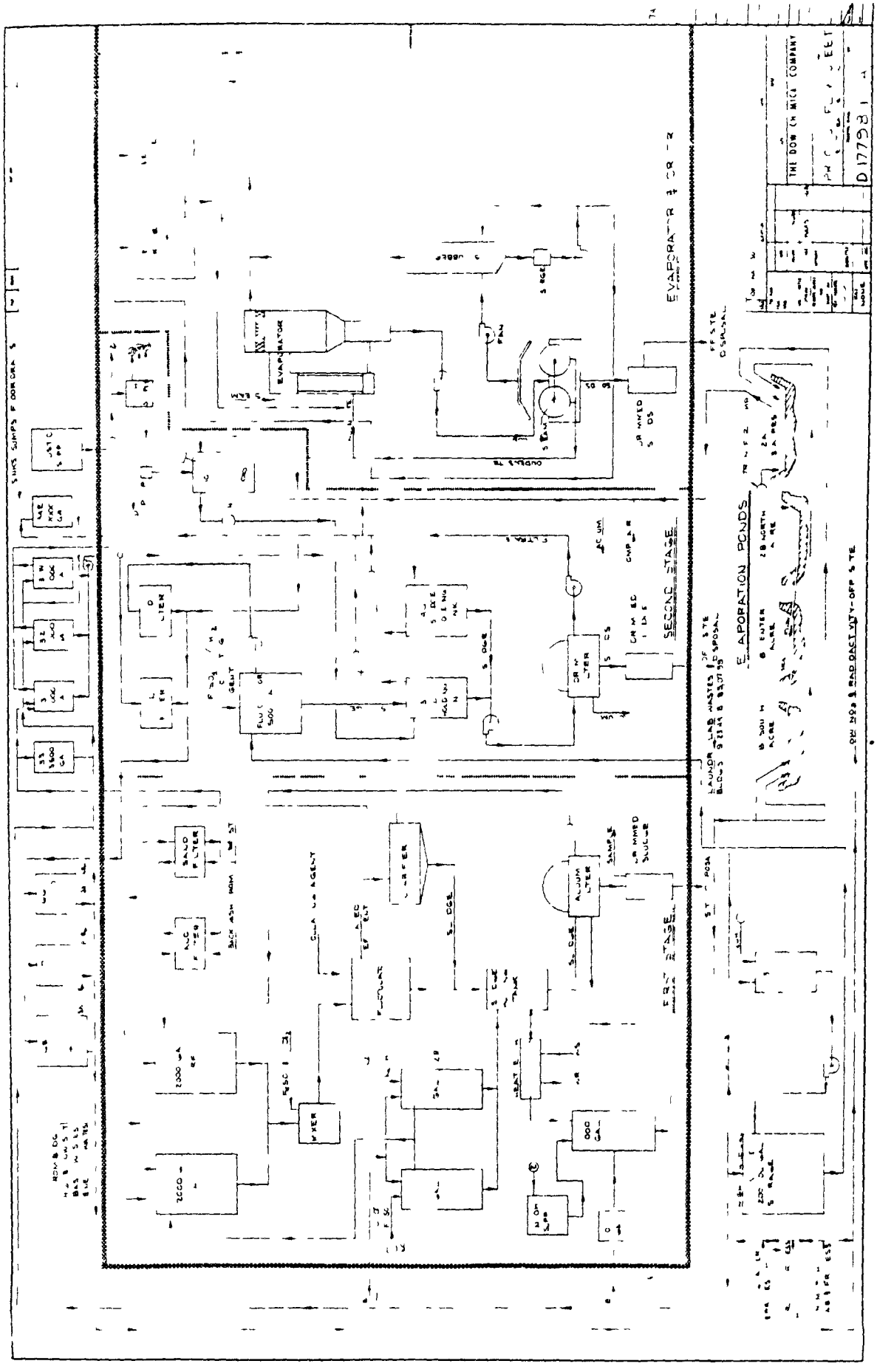
1. Routine monitoring of radioactivity levels in water in the effluent to Walnut Creek, Walnut Creek (at Indiana Street culvert) and Great Western Reservoir should include determinations of suspended and dissolved radioactivity, not total radioactivity in the unfiltered sample.

2. In addition to gross alpha activity determinations, specific analyses should be conducted for plutonium-239 and uranium.

5 At least annually, preferably semi-annually, levels of plutonium in the various trophic levels of the aquatic populations inhabiting Great Western Reservoir and Standley Lake should be determined

Semi-annual monitoring reports should be expanded to include data on effluent flow and radioactivity concentrations in the effluent to the south fork of Walnut Creek. Sufficient data should be presented to permit the calculation of at least the monthly amounts (curies) of plutonium and uranium (suspended and dissolved) discharged to the creek

Any recurrence of "incidents" resulting in on-site contamination cannot be tolerated, irrespective of the associated level of off-site contamination - negligible or of potential public health significance. Whatever preventive measures and/or facilities are considered necessary for the absolute prevention of incidents resulting in the venting of radioactive materials to the atmosphere must be implemented and/or installed. Remoteness of location is not a safety factor in this particular case, and this must be reflected accordingly in the operational aspects and safety program of the plant.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THE DOW CHEMICAL COMPANY
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COLORADO HEALTH
4210 EAST 11TH AVENUE DENVER, COLORADO 80220 PHONE 388-6111
R L CLEERE M D M P H DIRECTOR

June 9, 1970

Enclosed are copies of the latest surveillance information on the Rocky Flats Plant You will note the soil sample results clearly indicate the distribution of the ^{239}Pu contamination

Before briefly describing the soil analysis results, it might be well to first explain the sampling technique used

The U S P H S. obligated themselves to analyze 25 total samples for ^{239}Pu and ^{90}Sr content This was because the plutonium analysis, in particular, is extremely time consuming and they, of course, have other commitments for other surveillance activities. To take full advantage of this limited number of analyses, it was decided that a composite sampling program was indicated As you can see by the map attached to the soil analysis results, the area around the Rocky Flats Plant was divided into 13 sectors These sectors were located at 1, 3 and 6 mile distances from the plant boundary Twenty-five soil samples were collected in each sector with 20% or 5 separate samples collected additionally in each secto and retained for future reference Each location sampled is approximated on the map. The number of composite soil samples in the designated area totaled 325 Composite sediment samples of significant water bodies totaled 190 The soil samples collected were of the top 1/8" of undisturbed soil which would be indicative of the most severe health hazard in regard to re-suspension from the soil to the air.

It is interesting to note the similarity of results of the 75 background samples collected in Limon, Loveland and Penrose areas using the same composite sampling technique as described above Although we plan to expand the number of backgroun sampling areas, we anticipate that the present samples accurately describe the ^{239}Pu "background" levels on the Eastern Slope These levels are due almost entir from fallout from past atmospheric nuclear testing

Also worthy of note, are the results of the ^{90}Sr analyses and the $^{239}Pu/^{90}Sr$ ratio for sector soil samples, "background" soil samples and sediments These results would indicate that the ^{239}Pu results alone are the best indicator of the effect that the Rocky Flats Plant has had on the environment

It is our conclusion that no public health hazard now exists from past releases from the Rocky Flats Plant It would be impossible, however, to estimate any hazard which existed in the past. The highest concentrations were found adjacent to the plant at the eastern boundary This area is directly downwind from the area that the leakage of plutonium-contaminated oil and subsequent soil contamination occurred sometime during the period of 1955 through 1967 The main oil spill area was covered with asphalt in September, 1969 and an apron of 3" of base course material was completed around this area in March, 1970 The plutonium levels in the soils in this area were high and the material was carried downwind The elevated ^{239}Pu levels in Sectors 1, 2, 6 and 7 are primarily the result of this "incident "

Sector 2, which has the highest concentration of ^{239}Pu, can best be described as a non-populated area, access to which is not controlled In a paper by R L Kathren (1968), which was an extensive review of work done on plutonium contamination, "interim acceptable surface contamination levels for environmental PuO_2" are proposed. Based on dose to pulmonary lymph nodes, the following would be acceptable levels for occupancy by the general public

Urban areas	10 dpm/cm^2
Rural areas	100 dpm/cm^2

ICRP Publication 14 (1969) states that the dose limit for plutonium on the basis of risk to lymphoid tissue is not warranted. Adjustment of the above proposed acceptable levels would be upward by a factor of 2 or more Based on the conservative numerical terms used by Kathren, the level identified in Sector 2 (8 dpm/cm^2) is safe (acceptable) by at least a factor of 25 If the entire 13-sector area (0.3 dpm/cm^2) is used, the factor would range from 70 to 700 depending on whether the entire area would be considered as urban or rural, respectively Less conservative limits would, of course, provide a greater factor, and several of these were reviewed.

Extrapolation of the data indicates that the total ^{239}Pu soil contamination of the environment around the Rocky Flats Plant attributable to the plant approximates 0 3 Curie (4 9 grams ^{239}Pu) at the present time, 57% of which is located in Sector 2

Because hazard analysis based on soil data utilizes arbitrary re-suspension and "air concentration half-life" factors, the only proper method to thoroughly evaluate the situation is by air surveillance

The Department's plans are to continue, and in some cases increase, air surveillance activities downwind from both the contaminated area and the plant in general, and to work with Rocky Flats personnel in an effort to more fully identify and control any potential contaminant releases from the plant Samples from Sector 2 will be collected and analyzed to determine the long-term characteristics of ^{239}Pu in soils,

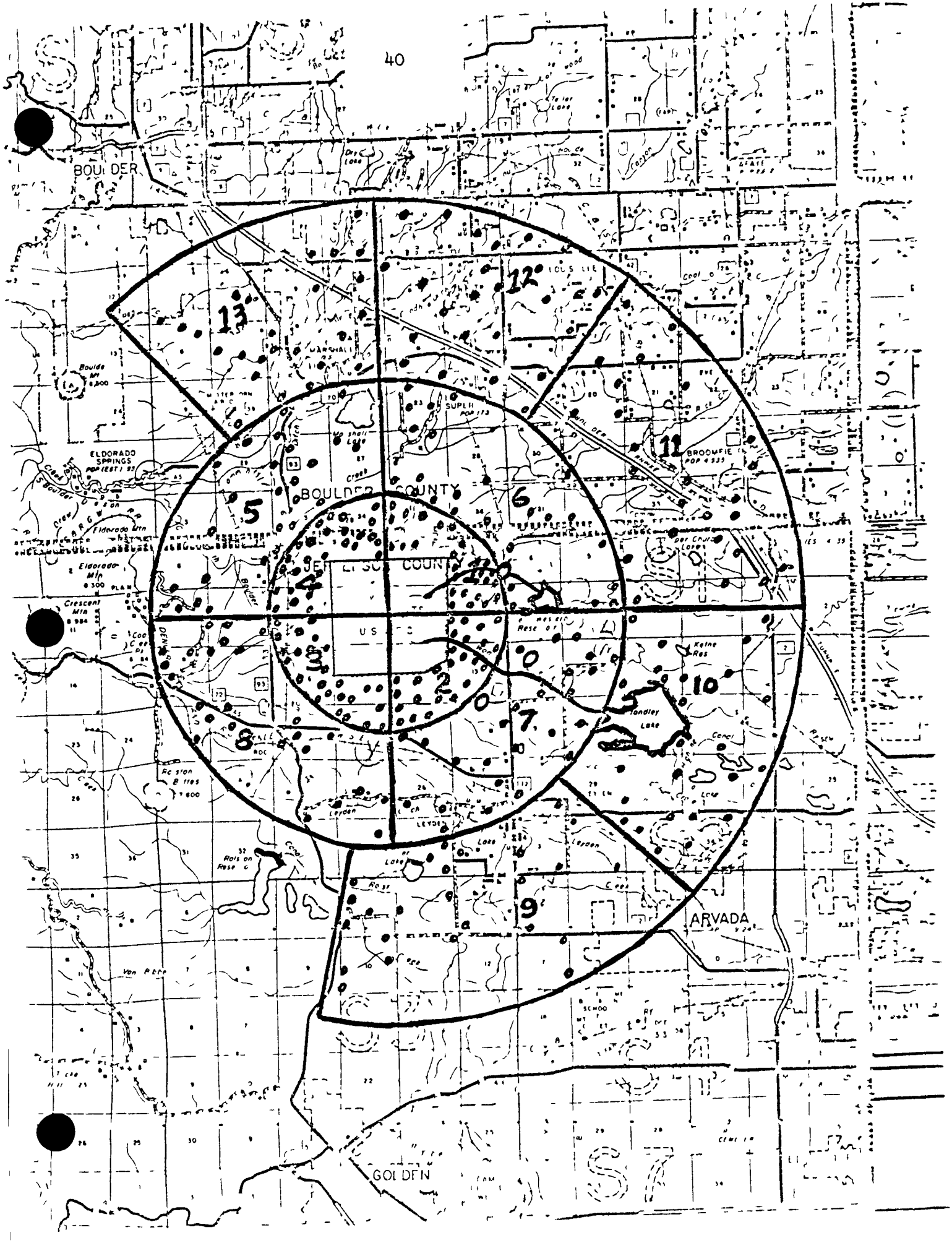
and of course as previously mentioned, an expanded effort will be made to establish an existing ^{239}Pu "background" for Colorado With the provision of additional funds, a higher percentage of samples (air, water and soils) will be analyzed for ^{239}Pu, thereby giving the Department an independent capability for hazard analysis, and definition of plant releases

If you have any questions regarding this matter, please let us know

Sincerely,

P W. Jacoe, Director
Division of Air, Occupational,
and Radiation Hygiene

PWJ/md
Enclosures


BOULDER
BOULDER COUNTY
JEFFERSON COUNTY
ARVADA
GOLDEN
ELDORADO SPRINGS
BROOMFIELD
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13

U S P H S - SWRHL Analysis
Soil & Sediment Sampling Results

SOILS

Backgrounds Sample Date	Location	dpm/g dry soil ^{239}Pu	^{90}Sr	Ratio Pu/Sr
2/18/70	Limon, Colorado	0.13	2 9	0 045
2/18/70	Loveland, Colorado	0 11	1.8	0.061
2/18/70	Penrose, Colorado	0 11	1 6	0 069
Samples				
2/18/70	Area 1	5 55	2 4	2 31
2/19/70	Area 2	24 4	2 4	10 2
2/18/70	Area 3	0 29	3 3	0 088
2/18/70	Area 4	0 31	3 6	0.086
2/18/70	Area 5	0 24	15 8	0 015
2/18/70	Area 6	1 00	1 6	0 625
2/19/70	Area 7	1 02	1 3	0 785
2/18/70	Area 8	0 04	1 1	0 036
2/18/70	Area 9	0.02	< 0.4	0 050
2/17/70	Area 10	0.38	< 0.4	0 950
2/18/70	Area 11	0 07	0 9	0.078
2/17/70	Area 12	< 0.02	0 9	0.022
2/19/70	Area 13	0.04	1 1	0.036

SEDIMENTS

2/18/70	Upper South Walnut Creek	46.6	< 0 4	--
2/18/70	Walnut Creek	109.0	< 0.4	--
2/18/70	Pond Walnut Creek and Indiana	28.9	<0.4	--
2/18/70	Great Western Reservoir	0.53	0.4	--
2/18/70	Woman Creek	2.18	0.4	--
2/18/70	Mower Reservoir	0.89	< 0.4	--
2/18/70	Standley Lake	0.07	< 0 4	--
2/18/70	Pond West of Indiana and 96th	0 53	lost	--
2/25/70	Ralston Reservoir inlet	0 40	0.4	--
2/25/70	Ralston Reservoir high water mark at inlet	0.02	< 0 4	--
2/25/70	Ralston Reservoir 100 yds. from inlet	0.16	< 0.4	--

Notes

The soil was analyzed for strontium by acid leach and ion exchange and for plutonium by total dissolution, ion exchange and electroplating

The values that appear high were rechecked and the values confirmed.

All Strontium 89 concentrations were found to be less than 1 1 dpm/gm of dry soil

AJH vam 5/25/70

Total ^{239}Pu Activity By Sector

Sector	^{239}Pu dpm/g dry soil	^{239}Pu dpm/cm^2	Area m_1^2	cm^2	dpm x 10^{10}	C_1
1	5 55	1 78	2 1	5 4 x 10^{10}	9 59	0 0432
2	24.4	7 81	2.2	5.7 x 10^{10}	44 5	0 2005
3	0 29	0.09	2.1	5 4 x 10^{10}	0 501	0.0023
4	0.31	0.10	2 1	5.4 x 10^{10}	0 536	0 0024
5	0.24	0 08	9 4	2 4 x 10^{11}	1 84	0 0083
6	1 00	0 32	9 4	2.4 x 10^{11}	7 68	0 0346
7	1.02	0 33	9.4	2 4 x 10^{11}	7 83	0 0353
8	0.04	0.01	9.4	2.4 x 10^{11}	0 307	0.0014
9	0.02	0.01	16 1	4.2 x 10^{11}	0.269	0 0012
10	0.38	0 12	13.0	3 4 x 10^{11}	4 13	0 0186
11	0 07	0 02	13.0	3 4 x 10^{11}	0 762	0 0034
12	< 0.02	< 0 01	13 0	3 4 x 10^{11}	0 218	0 0010
13	0 04	0 01	13 0	3 4 x 10^{11}	0 435	0 0020
Totals	-	0 27	114 2	296 x 10^{10}	78 6	0 354
Bkg	0 12	0 04	-	-	11.4	0 051
Net (Dow soil contamination contribution)						0 30

0 30 C_1 ^{239}Pu x 16 2 gms $^{239}Pu/C_1$ ^{239}Pu = 4 9 gms ^{239}Pu

Analytical Methods

The analytical procedures used in this study are taken from the published literature with adaptation or modifications made in the pretreatment of the sample to fit the published analytical procedure The limit of detection is that limit which is defined in the National Bureau of Standards Handbook 86, page 26

Analyses for water were done on the dissolved portion only, that is, the portion which passes through a 0.45 μ porosity millipore filter Soils and sediment samples were dried at 105° - 110°C, ground and sieved to 100 mesh.

Gross Alpha Analyses

One hundred milligrams of dissolved solids or sediment were transferred to a stainless steel planchet, distributed evenly, fixed by a dilute lucite solution, and alpha counted in an internal proportional counter The background count rate was nominally 0.1 cpm and the detection efficiency, based on a radium-226 standard, was nominally 30% The limit of detection for water samples varied with dissolved solids concentration, ranging from 1 - 4 pCi/l, and for sediment and soil samples, 1 4 pCi/g.

Total Alpha Radium

The procedure used was that of Goldin,[8] with modifications made for the pretreatment of sediment and soil samples. This modification consisted

of fusion of the sample using the flux described by Rushing[9] The limit of detection, based on a radium-226 calibration standard, is 0 1 pCi/g and 0 1 pCi/l, respectively, for sediment and water samples

Uranium

The procedure used for water analysis was essentially that of Edwards[10] Soils and sediments were acid leached and the uranium extracted into ethyl acetate from an acidified magnesium nitrate solution Uranium is determined fluorometrically[11] using a standard addition technique rather than by alpha spectroscopy Limits of detection (10% full scale, using 0 05 µg standard) are 0 3 µg/l and 0 3 µg/g for water and sediment, respectively

Strontium-90

The procedure used was taken from Krieger et al[12] and Velten[13] Pretreatment of sediment and soil samples consisted of acid leaching with 6N HCl, using a Soxhlet extractor Limits of detection are 0 1 pCi/g and 0 3 pCi/l for sediment and water, respectively

Plutonium

Pretreatment of sediment and soil samples consisted of acid leaching with 6N HCl,[14] using a Soxhlet extractor, and ultimate conversion to the nitrates by repetitive evaporation with nitric acid Water samples are evaporated to dryness and treated with nitric acid Plutonium is oxidized and extracted from 4N nitric acid into 0 1 M tri-n-octylphosphine oxide[15] Plutonium is reduced and back extracted and counted in an internal proportional counter Limits of detection are 0 02 pCi/g and 0 02 pCi/l for sediment and water, respectively

Tritium

This procedure is taken from Krieger et al,[12] with the exception that the volume ratio of scintillator to sample is increased to 5:1

Limit of detection is 400 pCi/l.

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DOCUMENT D-2

"Radioactivity Levels in the Environs of the Rocky Flats Plant, Golden, Colorado, 1970, Part II"
(1973)

by

U S Environmental Protection Agency

RADIOACTIVITY LEVELS

IN THE

ENVIRONS OF THE ROCKY FLATS PLUTONIUM PLANT

COLORADO

1970

PART II

December 15, 1973

TECHNICAL INVESTIGATIONS BRANCH
SURVEILLANCE AND ANALYSIS DIVISION
U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION VIII

FOREWORD

This report presents the findings of the September 1970 environmental radiation study conducted in the environs of the Rocky Flats Plutonium Plant (near Golden, Colorado). The field study and subsequent laboratory analyses were conducted by the staff of the Radiological Activities Section, Division of Technical Support, Water Quality Office, Environmental Protection Agency, Cincinnati, Ohio (an organizational unit of the Federal Water Quality Administration at the time of the study, reorganized into EPA in December 1971) Due to personnel transfers and changes in program responsibilities, a report on the study was not completed by the Radiological Activities Section prior to its dissolution from the EPA organizational structure during the first half of 1973. Since the primary investigators are now members of the Technical Investigations Branch, Surveillance and Analysis Division, and the environmental impact of the Rocky Flats Plant is a Region VIII concern, publication is undertaken as a regional responsibility.

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INTRODUCTION

During the week of February 20, 1970, representatives of the Federal Water Quality Administration visited the Rocky Flats Plant of the Atomic Energy Commission (located approximately 21 miles northwest of Denver, Colorado, between Golden and Boulder) The purpose of the visit was to obtain information on liquid radioactive waste management practices at the facility and the environmental surveillance activities in the plant environs Coincidently with the site visit, limited water and bottom sediment sampling was conducted to obtain independent data on plutonium levels in surface waters receiving drainage (liquid wastes and land runoff) from the site and in other nearby lakes. The findings of the investigation were reported previously in 1971 (1)

As a follow-up to the February 1970 investigation, an intensive field study was conducted during the period of September 21-25, 1970. The basic objectives were to determine plutonium levels in the resident biota of Great Western Reservoir and Standley Lake and the overall distribution of plutonium in the bottom sediment of Great Western Reservoir. At least to the date of the study, off-site surveillance by the plant contractor, Dow Chemical Company, was limited to water and soil sampling, plutonium in aquatic biota was a monitoring void Stations on Walnut Creek and Woman Creek, including Mower Reservoir, were revisited to obtain additional data on plutonium in bottom sediment and document changes which had occurred in the intervening seven month period

By virtue of the fact that this report presents the findings of the September 1970 study, it constitutes a supplement to the previous April 1971 report

SAMPLING PROCEDURES

Sampling stations for water, benthic organisms (benthos), and bottom sediment are listed in TABLE I and shown in FIGURES I-III. With the exception of sediment and benthos collection stations on Great Western Reservoir and Standley Lake, the sampling locations were identical to those established during the February 1970 study As noted in the preceding section, all samples were collected during the period of September 21-25

Water sampling was limited to three stations (TABLE I) with a daily grab sample (approx 4 liters) collected at each station throughout the study period It was assumed that samples collected from the shallow water at the dam faces were representative of the raw water pumped to the treatment plants serving the cities of Broomfield (Great Western Reservoir) and Westminster (Standley Lake) Uranium and plutonium analyses were conducted on composite (3 or 5 days) or the separate grab samples

Bottom sediment samples were collected from Great Western Reservoir and Standley Lake (FIGURES II and III) with dredges, Petersen or Eckman, and a core sampler. At all other stations (creeks or impoundments), sediment samples were collected by scraping the bottom area below the water line with a hand trowel The use of the hand trowel probably produced samples more representative of a thinner surface layer than those obtained with a dredge, particularly the Petersen dredge Similar to the collection of sediment samples, benthos samples were collected with dredges These samples were sieved in the field using a U S Standard No 30 sieve All material retained on the sieve was preserved in a 5% formalin solution for subsequent sorting and identification of the invertebrates and plutonium analysis

Fish samples were collected with electro-fishing equipment from the shallow water areas near the dam and inlet of both Great Western Reservoir and Standley Lake. The fish were placed on ice immediately after collection and maintained in a frozen state until processed for plutonium analysis A list of the species collected from each area is presented in TABLE II

Soil samples were collected at two of the three stations previously sampled in February

(1) Grazed area just to the southeast of the road culvert conveying Woman Creek under Indiana Street.

(2) Ungrazed area near the southeast corner of Great Western Reservoir

These samples were collected with a hand trowel to a depth of 1/8-1/4 inches

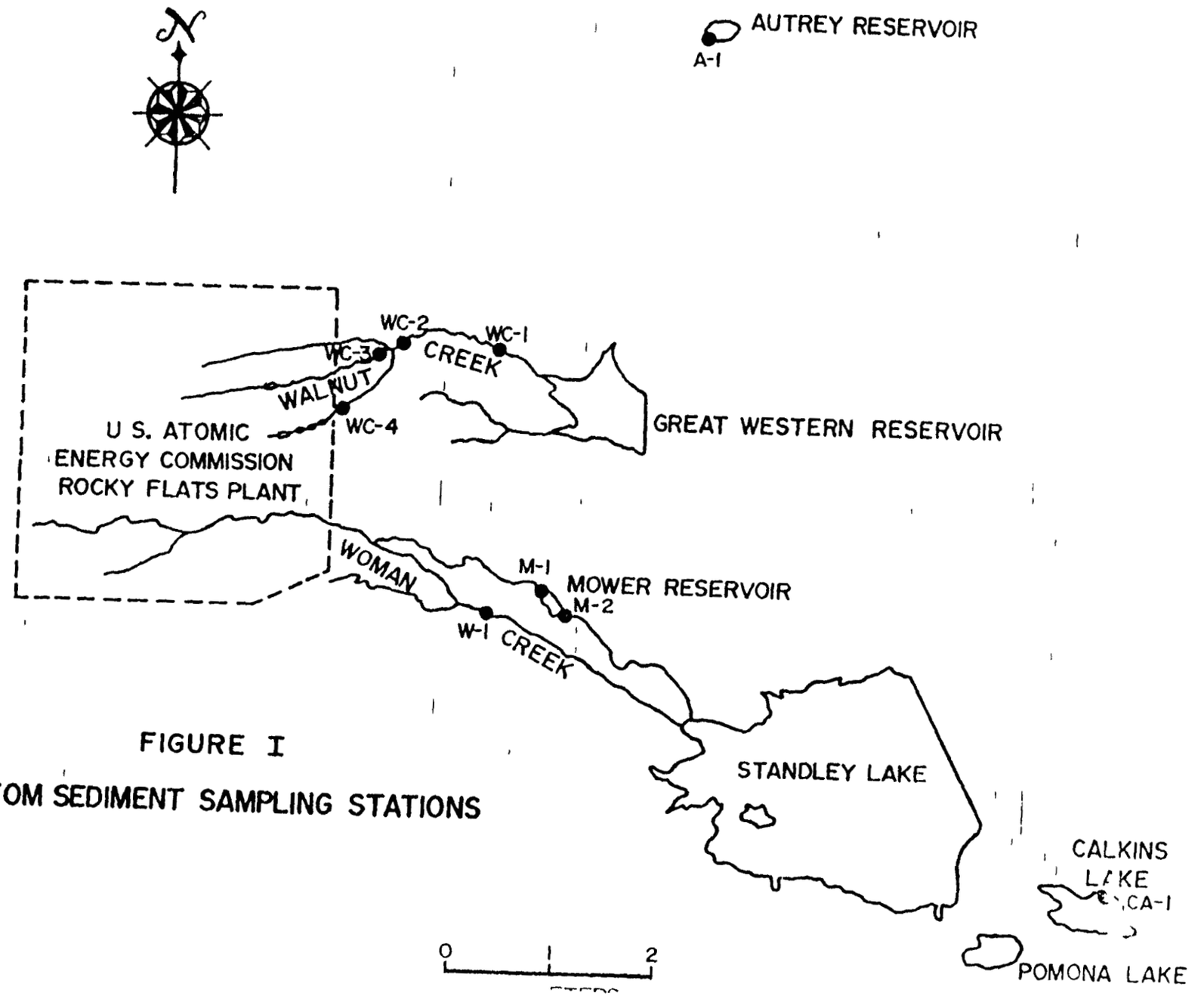

FIGURE I

BOTTOM SEDIMENT SAMPLING STATIONS

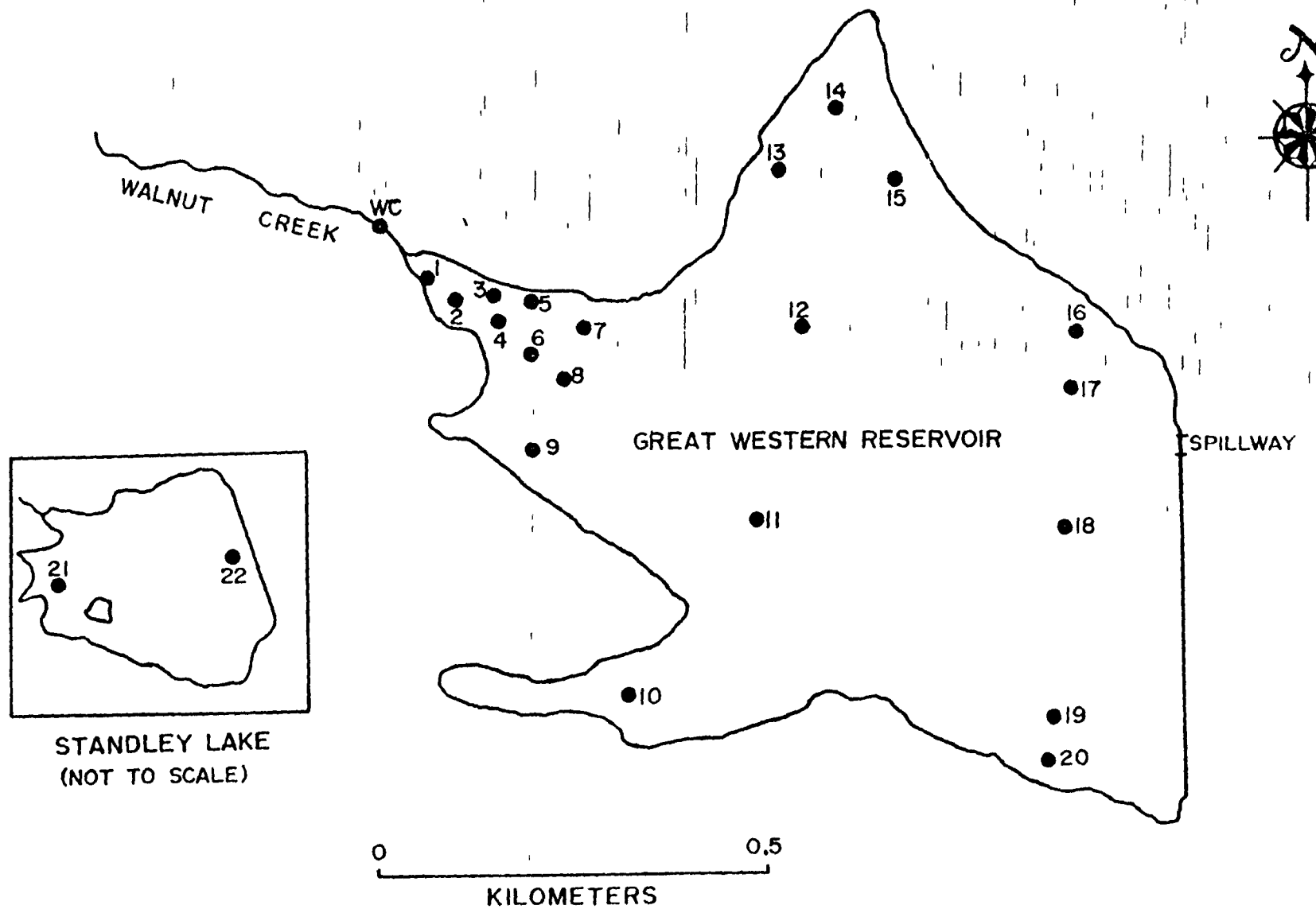

FIGURE II

SAMPLING STATIONS FOR BOTTOM SEDIMENT & BENTHIC INVERTEBRATES

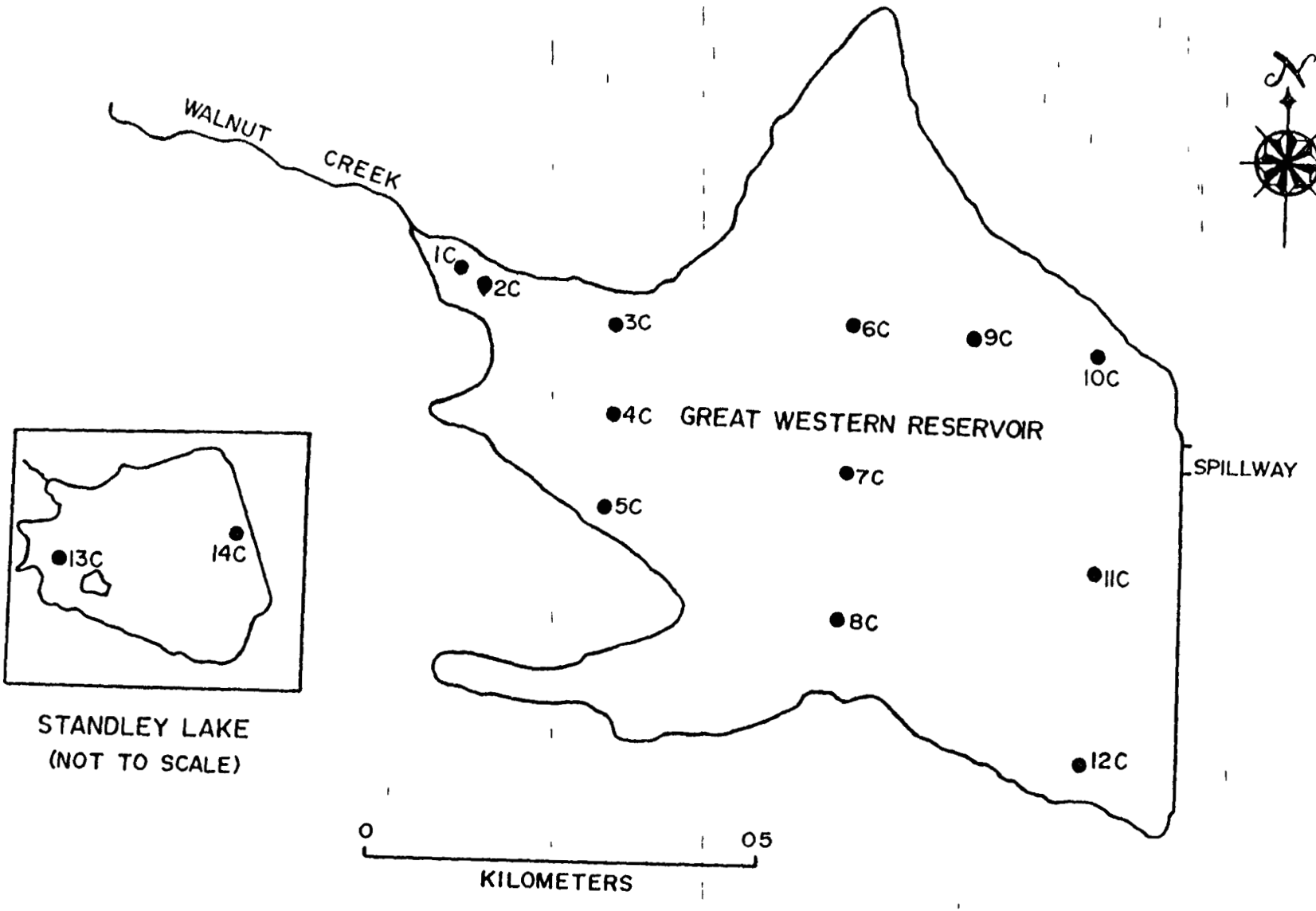

FIGURE III

SAMPLING STATIONS FOR CORE SAMPLES
GREAT WESTERN RESERVOIR & STANDLEY LAKE

TABLE I

SAMPLING STATIONS

Sample Type	Station Number	Description
Water	WC-1	Walnut Creek at Indiana Street
	-	Great Western Reservoir at dam face
	-	Standley Lake at dam face
Bottom Sediment	A-1	Autrey Reservoir, approximately 4 miles northeast of plant, Boulder County
	CA-1	Calkins Lake, north shore
	W-1	Woman Creek at Indiana Street
	M-1	Mower Reservoir at mouth of diversion ditch, west end
	M-2	Mower Reservoir, east end at dam face
	WC	Walnut Creek at mouth, inlet of Great Western Reservoir
	WC-1	Walnut Creek at Indiana Street
	WC-2	Main stem of Walnut Creek, 50 feet downstream of confluence of south fork with middle and north forks
	WC-3	Middle fork of Walnut Creek, 50 feet upstream of confluence with north fork
	WC-4	South fork of Walnut Creek at site boundary
	1-20 & 1C-12C	Great Western Reservoir
	21, 22, 13C, & 14C	Standley Lake
Benthos	1, 3-12, & 14-17	Great Western Reservoir
	21 & 22	Standley Lake
Fish	-	Great Western Reservoir, inlet and near dam face
	-	Standley Lake, inlet and near dam face

TABLE II

ELECTRO-FISHING - SPECIES OF FISH

Location	Species
Great Western Reservoir	
(A) Near inlet	Carp Northern Common Shiner Western White Sucker
(B) Near dam	Carp Green Sunfish Johnny Darter Northern Common Shiner Western White Sucker
Standley Lake	
(A) Near inlet	Carp Green Sunfish Large mouth Bass Northern Common Shiner Western White Sucker Yellow Perch
(B) Near dam	Black Bullhead Carp Green Sunfish Large mouth Bass Yellow Perch

RESULTS

Analytical results for water, bottom sediment, benthos, and fish samples are presented in TABLES III-VII With the exception of water samples which were analyzed for both dissolved plutonium and uranium, radiological analysis was limited to the measurement of plutonium Analytical procedures were the same as those described in the April 1971 report (1)

Water

Plutonium and uranium in the water samples from Walnut Creek, Great Western Reservoir, and Standley Lake were essentially at baseline levels (TABLE III) and relatively unchanged from February 1970 levels Dissolved uranium concentrations were less than 2.5 µg/l, typical of natural background in surface waters Dissolved plutonium concentrations were less than 0 03 pCi/l which was considered in 1970 to be a baseline condition attributable to atmospheric fallout In comparison with the February 1970 results, the only difference was the absence of an elevated uranium concentration in Walnut Creek (at Indiana Street) originating from plant waste discharges However, this finding is not of great consequence since the elevated concentration observed in February was not large and could be questioned as a normal variation in background

As a matter of general interest, surface runoff from rainfall was the reason for the high suspended solids concentration in Walnut Creek on the last day of sampling, September 25

Bottom Sediment and Soil

In terms of a general comparison among stations sampled during both the February and September studies, plutonium levels in sediment collected in September (TABLE IV) were equal to or less than the corresponding February results Considering the two impoundments assumed to be free of any impact from emissions from the Rocky Flats Plant - Calkins Lake and Autrey Reservoir, plutonium concentrations in sediment were 0 04 and 0 07 pCi/gram, respectively These data were identical with the February results, reaffirming the conclusion that the baseline concentration in the bottom deposits of area surface waters was $\leq$ 0 10 pCi/gram From the standpoint of absolute values, sediment from Mower Reservoir exhibited an apparent two-fold increase in plutonium between February and September However, it seems likely that this was a pseudo-increas attributable to normal concentration variations and the relative imprecision of the soil sampling procedure, particularly in an area of low contamination

Sharp reductions in the plutonium content of Walnut Creek sediment were observed in September This is illustrated by the following comparative tabulation of data from the two studies conducted during 1970

TABLE III

RADIOACTIVITY IN WATER SAMPLES

Station	Date	Suspended Solids (mg/l)	Plutonium Content of Suspended Solids (pCi/gram)(a)	Dissolved Plutonium (pCi/l)	Dissolved Uranium (µg/l)
Walnut Creek at Indiana Street (WC-1)	9/21-23 (Composite)	89	10	0.02	1 6
	9/24	53	15	<0 03	1 3
	9/25	390	3	<0.03	0 3
Great Western Reservoir at dam face	9/23-25 (Composite)(b)	13	<10	<0 02	2 1
Standley Lake at dam face	9/21-25 (Composite)	5	-	<0 01	2 4

(a) Dry weight basis
(b) No analysis for samples collected on 9/21 and 22

TABLE IV

PLUTONIUM IN BOTTOM SEDIMENT SAMPLES

Station	Station Number	Water Depth (meters)	Plutonium Content (pCi/gram)[a]
Autrey Reservoir	A-1	-	0 07
Calkins Lake	CA-1	-	0 04
Walnut Creek			
South fork at site boundary	WC-4	-	0.14
Middle fork	WC-3	-	0 16
Main stem, below confluence with middle fork	WC-2	-	0.29
Indiana Street	WC-1	-	0 60
At mouth	WC	-	0 26
Great Western Reservoir	1	0.61	0 34
	2	0.92	0 86
	3	-	0 49
	4	0.92	0.57
	5	-	0 58
	6	-	0 34
	7	-	0 61
	8	3 05	0 52
	9	1 52	0 30
	10	1 98	0 25
	11	6 71	0 57
	12	4 88	0 08
	13	1 83	0.16
	14	-	0 15
	15	1 83	0 14
	16	4.57	0 10
	17	15.0	0.08
	18	16 5	0 31
	19	7.32	0 18
	20	1.68	0 12
Woman Creek at Indiana Street	W-1	-	0 20
Mower Reservoir			
West end	M-1	-	0 18
East end	M-2	-	0 18
Standley Lake	21	3.05	0.05
	22	19.2	0 21

(a) Dry weight basis

TABLE V

PLUTONIUM IN BOTTOM SEDIMENT CORE SAMPLES

Station	Station Number	Water Depth (meters)	Section Analyzed (inches)(a)	Plutonium Content (pCi/gram)(b)
Great Western Reservoir	1C	0 76	0-1	0 36
			1-2	0 58
			2-3	1 0
			3-5 25	0 43
	2C	0 76	0-1	0 44
			1-2	0 71
			2-3	0 26
	3C	2 14	0-1	0 38
			1-2	0 29
			2-3	0 19
	4C	1 37	0-1	0 10
			1-2	0.09
	5C	2 14	0-1	0 09
			1-2	0 04
			2-3	0 07
	6C	3 05	0-1	0 06
			1-2	0 06
	7C	7.77	0-1	0 27
			1-2	0 34
			2-3	0 06
			3-4	0 09
	8C	6 40	0-1	0 41
			1-2	0 29
			2-3	0 05
	9C	11 9	0-1	0 42
			1-2	0 26
			2-3	0 07
			3-4.25	0 07
	10C	11 0	0-1	0 09
			1-2	0 03
	11C	15 2	0-1	0 33
			1-2	0 27
			2-4	0 11
			6-7	0 41
			7-8	0 40
			13-14 5	0 06
	12C	5 49	0-1	0 08
			1-2	0 03
Standley Lake	13C	3 05	0-1	0 09
			1-2	0 11
	14C	19 2	0-1 25	0 28
			1 25-2 25	0 22
			2 25-3 25	0 13
			3 25-4 25	0 32
			7 25-8 25	0 12
			11 25-12 25	0 37
			12 25-14 75	0 18
			14 75-15 75	0 11

(a) The limits of the range are measurements in inches from the top surface of the core sample No correction for compaction during sample collection (refer to Appendix B)

(b) Dry weight basis

TABLE VI

PLUTONIUM IN FISH

Station	Species	Number of Fish	Total Length (cm)	Organ	Sample Weight (grams)(a)	Plutonium Concentration (pCi/kilogram)(a)
Great Western Reservoir						
(A) Near inlet	Carp	15	45-85	Whole	52 0	<2 0
		3	283-364	Flesh	420	<0 3
			"	Liver	10 0	<20
			"	Bone	35 0	<4 2
			"	Roe	240	0 9
	Northern Common Shiner	153	30-81	Whole	171	9 6
	Western White Sucker	15	70-132	Whole	99	3 0
		8	140-272	Flesh	259	<0 6
			"	Bone	19 0	9 4
(B) Near dam	Carp	2	71	Whole	12 6	<7 0
		2	295&378	Flesh	318	<0 4
			"	Liver	5 0	<32
			"	Bone	27 5	<5 6
	Green Sunfish	32	31-48	Whole	27 0	<3 0
		56	49-76	Whole	196	1 0
		20	90-125	Flesh	146	<1 0
			"	Liver	6 0	30
			"	Bone	12 0	<14
		10	129-151	Flesh	163	<0 9
			"	Liver	8 0	<20
			"	Bone	19 0	<8 2
	Northern Common Shiner	50	30-75	Whole	79 6	3 7
	Western White Sucker	8	130-180	Flesh	115	<1 3
			"	Bone	10 0	<16
Standley Lake						
(B) Near inlet	Carp	2	329&390	Flesh	249	<0 7
			"	Liver	4 5	<37
			"	Bone	29 0	<5 8
	Green Sunfish	7	40-48	Whole	13 0	<13
	Largemouth Bass	7	61-90	Whole	45 0	<1 1
	Northern Common Shiner	9	55-74	Whole	27 0	<6 2
	Western White Sucker	1	83	Whole	158	<1 1
	Yellow Perch	25	46-70	Whole	50 0	<1 4
		4	106-130	Whole	72 0	<1 7
		6	171-231	Flesh	335	<1 1
			"	Liver	2 5	<73
			"	Bone	20 0	<8 4
(B) Near dam	Black Bullhead	1	165	Whole	125	<1 2
	Carp	4	335-368	Flesh	589	<0 3
			"	Liver	17 0	<9 9
			"	Bone	56 0	1 9
			"	Roe	32 0	14
	Green Sunfish	4	69-106	Whole	45 0	<3 4
		7	125-147	Flesh	95 0	1 8
			"	Liver	4 0	<18
			"	Bone	9 0	<19
		3	155-177	Flesh	89 0	<0 8
			"	Liver	4 0	<36
			"	Bone	13 0	32
	Largemouth Bass	3	43-59	Whole	→ Sample Lost →	
	Yellow Perch	1	106	Whole	15 0	<10
		5	160-192	Flesh	100	<1 5
			"	Liver	1 0	<160
			"	Bone	10 0	<17

(a) Live weight basis

TABLE VII

PLUTONIUM IN BENTHIC INVERTEBRATES

Station	Invertebrate	Sample Dry weight (mg)	Plutonium Concentration (pCi/gram)(a)
Walnut Creek at Indiana Street	Blackflies	2247	0 07
	Caddisflies	3511	0 08
	Mayflies	225 4	<0 4
	Midges	92 6	<0 9
	Other	83 3	<1 0
	Crayfish	12 4	None Detected
Great Western Reservoir			
Sta 1	Predominately Midges	6 4	55
	"	20 8	<5 0
	"	39 5	<2 0
Sta 4	Midges and Sludgeworms	2 9	<28
		11 1	<7 0
Sta 7	Midges and Sludgeworms	4 7	<17
		19 7	<5 0
Sta 8	Midges and Sludgeworms	4 7	<17
Sta 9	Midges and Sludgeworms	2 9	<27
		3 4	<23
Sta 10	Midges and Sludgeworms	0 9	<85
		1 8	<43
Sta 11	Midges and Sludgeworms	5 9	24
		9 0	<9 0
Sta 12	Predominately Sludgeworms	10 3	<8 0
		12 1	<7 0
Sta 13	Predominately Midges	3 0	<26
		8 6	<9 0
Sta 15	Damselflies, Scuds, Midges and Sludgeworms	6 1	<13
		11 3	<7 0
Sta 16	Predominately Sludgeworms	10 3	<7 0
		12 9	<6 0
Sta 17	Midges and Sludgeworms	3 5	<20
Sta 18	Midges and Sludgeworms	2 0	<35
		3 6	<20
Sta 19	Predominately Sludgeworms	19 8	<4 0
	Midges	21 5	4 0
Sta 20	Mayflies, Caddisflies, Scuds Midges, and Sludgeworms	3 4	<20
		18 3	<5 0
Standley Lake			
Sta 21	Midges and Sludgeworms	2 6	<33
		22 8	6
Sta 22	Predominately Sludgeworms	9 3	<9 0
		18 7	<5 0

(a) Dry weight basis

Walnut Creek Station	Plutonium Concentration (pCi/gram)	
	February	September
South fork at site boundary	3 51	0 14
Middle fork	0 50	0 16
Main stem, below confluence with middle fork	3 41	0 29
Indiana Street	0 92	0 60
At mouth, inlet to Great Western Reservoir	1 75	0 26

These data indicated scouring of contaminated sediment from the creek bed and/or coverage of contaminated zones by less contaminated soil washed into the creek without reaccumulation to previously observed maximal levels by mas transport from the aqueous phase. Assuming that the routine discharge of plutonium-bearing liquid wastes is the major source of sediment contaminat·or the reduced September concentrations were apparently the result of high flow shortly before the collection of samples Unfortunately, flow data required for a truly meaningful interpretation of the limited sediment data are not existent In the case of Woman Creek, no significant difference was observed between the February and September results - 0 23 and 0 20 pCi/gram, respectively

The results for "dredge" samples and the top one-inch sections of core samples showed that nearly the entire bed of Great Western Reservoir contains plutonium at concentrations in excess of the baseline value, ≤ 0 10 pCi/gram Plotted in FIGURES IV and V, only the extrapolated shaded areas represent bottom deposits containing 0 10 pCi/gram or less of plutonium The area or sector of greatest contamination appeared to be the central section of the reservoir (inlet to dam) with maximum concentrations near the inlet In the inlet area, the maximum concentration in the top one-inch section was 0 86 pCi/gram (Station 2) with an average concentration of 0 50 pCi/gram for Stations 1-8 and 1C-3C Sediment samples from the northern arm (Stations 13 14, and 15) showed plutonium concentrations only about 50% higher than the baseline value - average concentration of 0 15 pCi/gram for the three static Bank sloughing was observed in this arm

Core samples from Great Western Reservoir showed that the thickness of deposited plutonium-contaminated sediment was 2 inches or more at all locations (TABLE V) Near the face of the dam in the deep-water area, plutonium contamination on the order of four times the baseline level was found at a sediment thickness of 7 to 8 inches (Station 11C) At Station 10C, adjacent to Station 11C in the deep-water area, baseline concentrations were obtained from the core sample However, these findings are consistent when the differences in bottom conditions are taken into account Unlike Station 11C where the layer of "black" sediment was 8" thick (compacted in the core tub

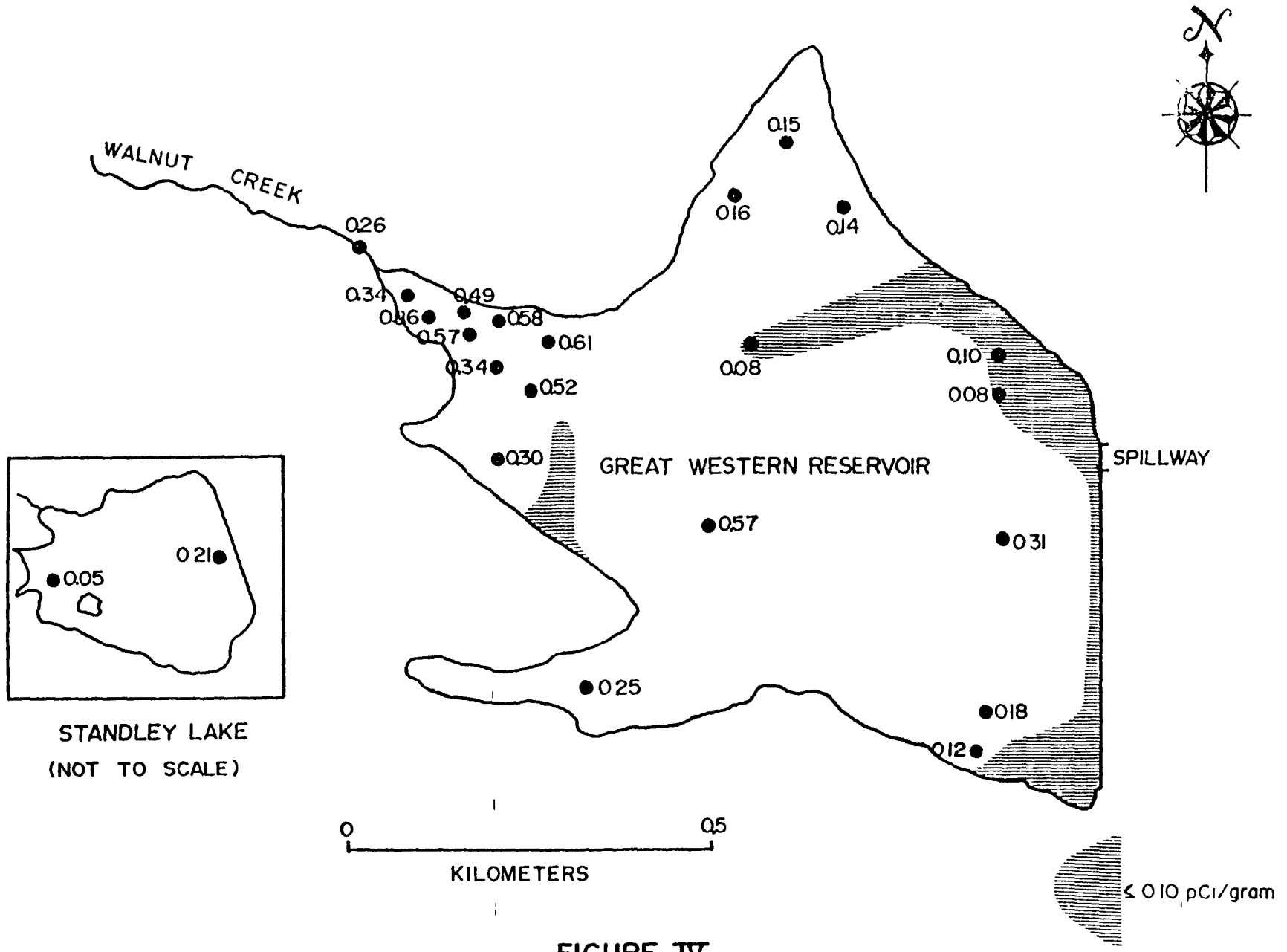

FIGURE IV

PLUTONIUM (pCi/gram) IN BOTTOM SAMPLES

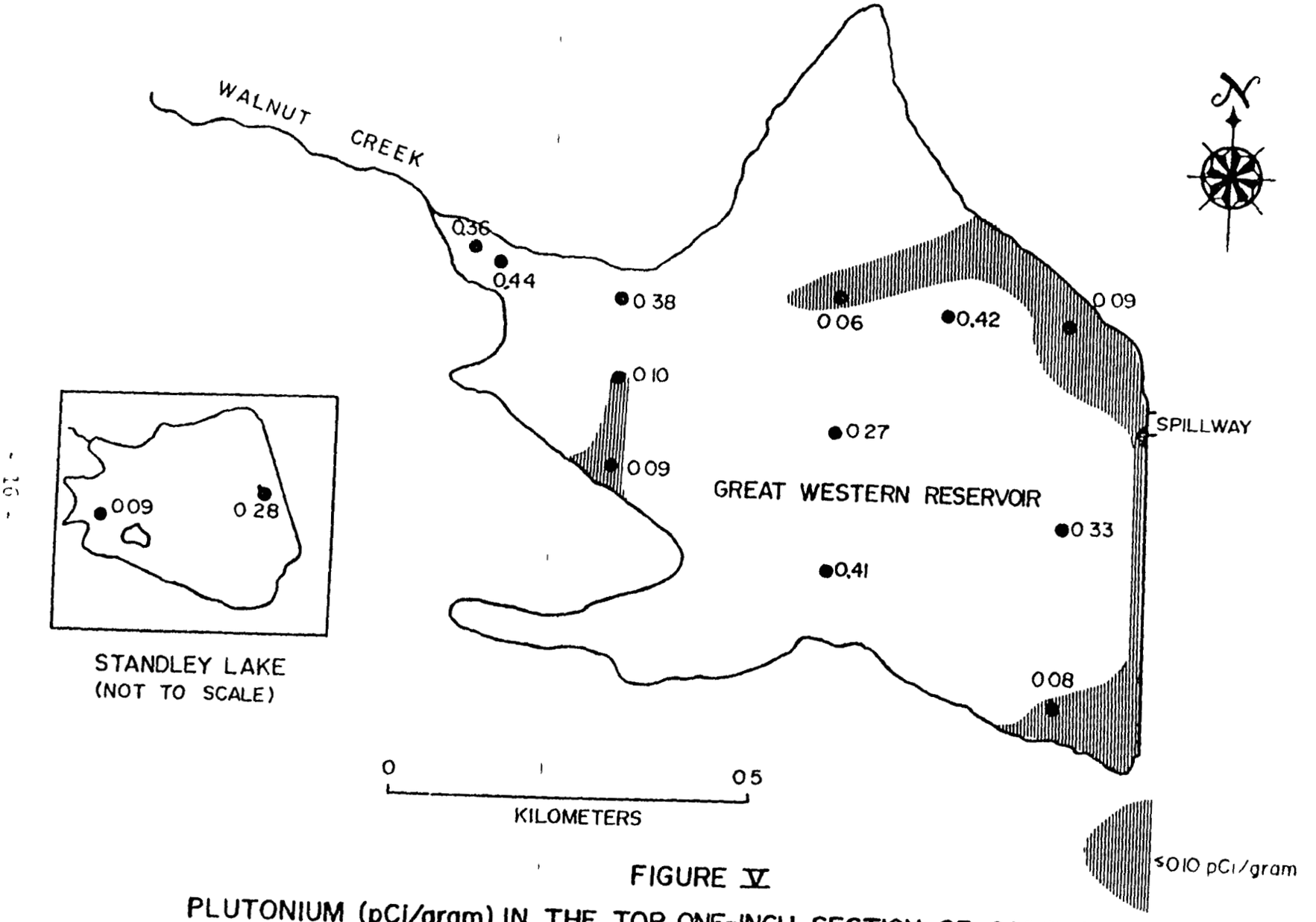

FIGURE V

PLUTONIUM (pCi/gram) IN THE TOP ONE-INCH SECTION OF CORE SAMPLES

GREAT WESTERN RESERVOIR & STANDLEY LAKE

only the top one inch section of the core collected at Station 10C was of similar composition. Below one inch, clay was found at Station 10C. The finding that plutonium contamination is not restricted to the surface-layer of bottom sediment suggests a contamination source of some duration, presumably, the continuously occurring discharge of liquid wastes from the Rocky Flats Plant.

Dredge and core samples from the west end of Standley Lake near the mouth of Woman Creek (Stations 13C and 21) showed baseline concentrations of plutonium (TABLES IV and V, FIGURES IV and V). In contrast, samples collected at Stations 14C and 22 - east end of the lake just offshore of the dam in the deep-water area, contained plutonium in concentrations on the order of two to three times baseline. Furthermore, the results for the several sections of the core sample showed that plutonium contamination was not limited to the surface, but extended to a thickness of approximately 12 inches (compacted in the core tube). Since plutonium-bearing liquid wastes are not and have not been discharged to Woman Creek, the origin of plutonium-contaminated sediment in Standley Lake would have to be contaminated soil transported and deposited in the lake by runoff. Although this is a plausible source for the contamination of the surface layer of sediment, it is not a good explanation for the finding of plutonium contamination to a thickness of several inches. To verify the existence of significant zones of plutonium-contaminated sediment in the lake, or disprove as the case might be, additional monitoring of a scope similar to that used for Great Western Reservoir will be required. Until this effort is undertaken, the results for Stations 14C and 22 will be subject to question on the basis of possible sample contamination.

Similar to the findings for bottom sediment samples from area surface waters, the two soil samples showed substantially lower plutonium concentrations in comparison to those collected from the same general locations in February.

Location	Plutonium Concentration (pCi/gram) February	September
Grazed area to the southeast of the road culvert conveying Woman Creek under Indiana Street	2.42	0.64
Ungrazed area near the southeast corner of Great Western Reservoir	0.42	0.14

Fish and Benthos

Information presented in the literature review of Olafson and Larson[2]

on the biology and environmental persistance of plutonium leads one to the conclusion that plutonium entering the Walnut Creek - Great Western Reservoir system as the result of liquid waste releases ultimately accumulates in the reservoir sediment with very little transfer to and cycling in aquatic biota Among the conclusions reached by Olafson and Larson, the following are pertinent to the Rocky Flats "situation "

(1) Plutonium is absorbed by plants growing on contaminated soil to an infinitesimal degree, although it may be found as an external contaminant on vegetation
(2) Ingested plutonium is absorbed and retained in animal tissues to only a very small degree
(3) Based on animal tissue assays, very little plutonium gains entry into mammalian systems

In animals, ingested plutonium concentrates in bone and liver tissue There is also concentration in reproductive tissue

The results for benthos and fish (TABLES VI and VII) generally showed that there was no significant accumulation of plutonium in the biota of Great Western Reservoir and Standley Lake As evidenced by the preponderance of "less than" results, small sample size, particularly in the case of benthos samples, prevented the conduct of analyses with the high degree of analytical sensitivity required for definitively determining absolute concentrations Excluding the five positive results, the "best" detection limit for benthos samples was about 40 pCi per kilogram (live weight)(a) whereas the desired sensitivity was within the range of 0 1 to 1 0 pCi/kg Furthermore, considering sample size, only the positive results for blackflies and caddisflies from Walnut Creek at Indiana Street should be given credence as valid, absolute concentrations

Although the analysis of fish samples also produced few absolute concentrations, larger sample sizes - gram amounts instead of milligrams - enabled the conduct of analyses with precision consistent with the range of expected low concentrations (refer to TABLE VIII - plutonium in foodstuffs reported in 1959 by the U S Atomic Energy Commission). Considering edible tissue (flesh), the plutonium concentrations in all species from both impoundments were less than 2 pCi per kilogram (live weight). Hence, human consumption of these fish would be insignificant from the standpoint of resultant radiation dose because the daily intake limit for the general public, as recommended by the National Committee on Radiation Protection(3), is approximately 3700 pCi of plutonium One finding of interest was the apparent accumulation of plutonium in carp roe Although beyond the scope of this report, this finding raises the question of a possible genetic effect on fish

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(a) Calculated on the basis of an assumed moisture content of 90%

TABLE VIII[a]

PLUTONIUM CONCENTRATIONS IN VARIOUS FOOD ITEMS AND PLANTS

Item	Plutonium-239 Concentration (pCi/kilogram)
Rain	0 18
Alfalfa ash	430 to 800
Milk	0 16
Wheat ash	130 to 670
Swordfish	0 34 to 1 0
Pork liver	0 56 to 2 7
Beef meat	0 19 (meat of chuck steak) 180 (fluid)

(a) TABLE 4 in Reference 2 (data from U S Atomic Energy Commission, Quarterly Statement on Fallout in "Fallout from Nuclear Weapons Tests Hearings before the Special Subcommittee on Radiation, Joint Committee on Atomic Energy, Congress of the U S., May 5-8, 1959," pp. 2188-2198, U S Government Printing Office, Washington, D C , (1959))

Aside from radiological considerations, benthos and plankton sampling showed the presence of pollution tolerant organisms in both Great Western Reservoir and Standley Lake, indicative of enriched or eutrophic conditions In the case of Great Western Reservoir, the contributing polluton sources are domestic-type wastes from the Rocky Flats Plant and agricultural runoff whereas only the latter is the source to Standley Lake The pollution biology aspects of the field study are presented in detail in Appendix A

SUMMARY

The September 1970 field study produced the following significant findings

(1) Almost the entire bed of Great Western Reservoir was covered with sediment containing plutonium in excess of the estimated baseline concentration, ≤ 0 10 pCi/gram The thickness of the layer of plutonium-contaminated sediment was 2 inches or more at all such sampling stations The maximum concentration of approximately 1 0 pCi/gram was obtained at the inlet area of the impoundment

(2) Limited sediment sampling in the deep-water area of Standley Lake indicated possible sectors of plutonium contamination attributable to past emissions from the Rocky Flats Plant

(3) Fish and benthos from Great Western Reservoir and Standley Lake did not show significant accumulation of plutonium In all species of fish, the concentration in flesh was <2 pCi/kilogram-live weight At this low concentration, human consumption at an abnormally high intake rate of one kilogram per day would be inconsequential in terms of radiation dose

In that this study was the initial comprehensive effort at determining plutonium concentrations in the biota and sediment of Great Western Reservoir and Standley Lake, additional monitoring will be necessary to determine the representativeness of the specific results as maximum, steady-state values or "points" on curves showing increasing or decreasing trends

REFERENCES

(1) Environmental Protection Agency, "Radioactivity levels in the Environs of the Rocky Flats Plutonium Plant, Golden, Colorado, 1970," Radiological Activities Section, Division of Technical Support, Water Quality Office (April, 1971)

(2) Olafson, J H , and Larson, K H , "Plutonium, Its Biology and Environmental Persistence," in "Radioecology," edited by V Schultz and A W. Klement, Jr , pp 633-639, Reinhold Publishing Corporation, New York, New York, and The American Institute of Biological Sciences, Washington, D. C , (1963)

(3) National Committee on Radiation Protection, "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure," U S Department of Commerce, National Bureau of Standards Handbook 69, U S Government Printing Office, Washington, D. C. (1959)

APPENDIX A

BIOLOGICAL STUDY OF GREAT WESTERN RESERVOIR -

A biological study was conducted on Great Western Reservoir during the week of September 21 to 24, 1970 Objectives of the study were to determine a) effects on the reservoir of domestic sewage discharged to Walnut Creek, a tributary to the reservoir, from the Rocky Flats Plutonium Plant, and b) the existing levels of plutonium in the sediments, benthic invertebrates, and fish in the reservoir

In a lake the clean water benthic community is usually composed of many kinds of organisms, each kind being few in number When domestic sewage is discharged to a lake, the number of kinds of benthic organisms are reduced and the remaining organisms are able to increase in number A lake receiving domestic sewage or runoff from surrounding agricultural areas may have an oxyger consuming layer of decomposing organic material Such a layer is caused by either an inflow of suspended organic matter which settles to the bottom or by the contribution of large amounts of nutrients which cause an increase in the plankton population during the spring and a resultant die-off and settling of the plankton each fall

The water layer above a bottom of decomposing organic material is usually low in dissolved oxygen and the bottom material supports only small numbers of pollution tolerant organisms

Methods

Samples of the benthic invertebrate populations were obtained from Walnut Creek and the reservoir with either a Petersen dredge or Eckman dredge Sampli stations are depicted in FIGURE II. Benthic invertebrates were collected from all stations except Stations 2, 3, 5, 6, and 14 Dredge samples were sieved through a U S Standard No 30 sieve and material retained on the sieve was preserved in five per cent formalin. All samples were picked and invertebrates identified in Cincinnati, Ohio

Short five-minute tows were made with a plankton net near the inlet and middle of Great Western Reservoir and near the middle of Standley Lake The concentrated plankton samples were examined to determine the qualitative composition of the algal populations in each water body

Results

The bottom sediments in Great Western Reservoir did not support large numbers of organisms (TABLE A-I and FIGURE A-I) Only in an area extending from the inlet of Walnut Creek and the offshore areas near the dam were the numbers of organisms large enough to merit mention (FIGURE A-I)

TABLE A-I

TOTAL NUMBER AND KINDS OF BOTTOM ORGANISMS COLLECTED FROM GREAT WESTERN RESERVOIR AND STANDLEY LAKE

	Walnut Creek	Great Western Reservoir															Standley Lake	
		1	3	4	5	6	7	8	9	10	11	12	14	15	16	17	33	34
Mayflies																		
Baetis sp	272	Q																
Caenis sp	5						Q											
Caddisflies																		
Chematopsyche sp	1924	Q					Q											
Neotrichia sp	12																	
Damselflies																		
Odonata		Q										Q						
Scuds																		
Hyalella sp	22						Q					Q						
Midges																		
Glyptotendipes sp							Q					Q		Q		7		
Cricotopus sp	411						Q					Q						
Spaniotoma sp	10																	
Chironomus sp	2	65	7	10	7	21	3			Q	4	Q	34	3	24	26		31
Procladius sp							1											
Cryptochironomus sp							11			2		5	Q					
Tanytarsus sp							8			2		3						
Biting Midges																		
Stilobezzia sp	10	Q																
Phantom Midge																		
Chaoborus sp						1		3	4								Q	
Mosquito																		
Culicinae					Q													
Blackflies																		
Simuliidae	1671																	
Snails																		
Physa sp	3																	
Sludgeworms	15	24	3	14	24	74	5	2	Q	72	46	19	2	10	5	19	16	10
Crayfish	2																	
TOTAL NUMBER	4359	89	10	24	31	96	28	5	4	76	50	27	36	13	29	52	16	4
TOTAL KINDS	13	6	2	2	3	3	10	2	2	4	2	8	3	3	2	3	2	2

Q = Organisms not collected quantitatively, arbitrarily given value of 1 for computing number of kinds

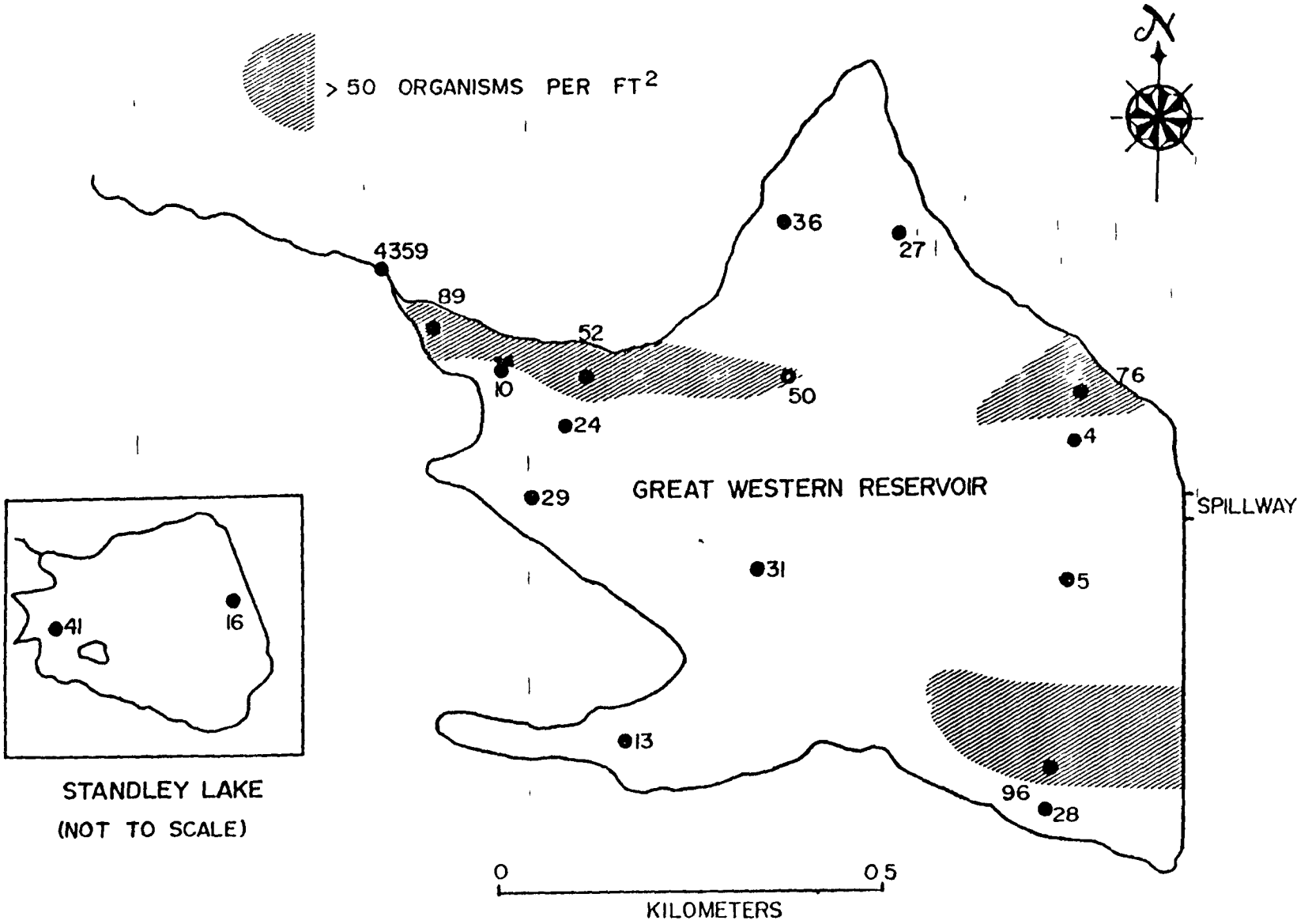


FIGURE A-I

DISTRIBUTION OF BOTTOM ORGANISMS PER SQUARE FOOT

The inlet (Station 1) supported a diverse population of organisms that received nutrients from Walnut Creek The creek supported an enriched community of 13 kinds of organisms numbering 4359 per square foot, an indication that nutrients discharged from the Rocky Flats Plutonium Plant affect the benthic community immediately upstream from the reservoir At the inlet or upper end of the reservoir (Station 1) the population of benthic organisms was composed of six kinds with a total number of 89 organisms per square foot, twice as many organisms per square foot as collected in the upper end of Standley Lake (Station 21) which is not reported to receive domestic sewage

Great Western Reservoir had low numbers of benthic organisms at all stations except Stations 12, 16, and 19, where the benthic community was predominately sludgeworms numbering 74, 72, and 46 square foot, respectively The larger numbers of sludgeworms at these stations as opposed to the other areas of the lake (TABLE A-I) were probably due to nutrients received from Walnut Creek Other areas of the reservoir that would have been affected by nutrients in runoff water, and not domestic waste, such as Stations 10, 13, and 15, did not support large numbers of sludgeworms The deep water area of the Great Western Reservoir represented by Stations 17 and 18 supported only small numbers of pollution tolerant midges and sludgeworms (TABLE A-I, FIGURE A-I) The reduced number of organisms in this area of the reservoir was caused by the presence of a layer of black decomposing organis material on the bottom Cores of the bottom material revealed 9 to 21 inches of black sediment covering the bottom Bottom samples had a slight hydrogen sulphide odor Since a similar black organic material was collected at Station 22 in Standley Lake, the assumption must be made that both lakes receive nutrients and organic material from land runoff and such material settles in the deeper areas where it decomposes In the case of Great Western Reservoir, the nutrients received from Walnut Creek add to the effects of nutrients from agricultural drainage, thus affecting a larger area of the reservoir

In the plankton samples from Great Western Reservoir, filter-clogging organisms such as Melosira sp abundant, and taste and odor organisms such as Staurastrum sp. and Ceratium sp were present, indicating possible water treatment problems Pollution tolerant Microcystis sp was also present, and indication that the reservoir water contained excessive amounts of nutrients Standley Lake phytoplankton were predominantly composed of the pollution tolerant algae Microcystis sp and Anabaena sp , indicating the lake has received enough nutrient from agricultural runoff to become highly enriched or eutrophic

DOCUMENT D-3

"Plutonium Levels in the Sediment of Area Impoundments
Environs of the Rocky Flats Plutonium Plant - Colorado"
(1975)

by

U S Environmental Protection Agency

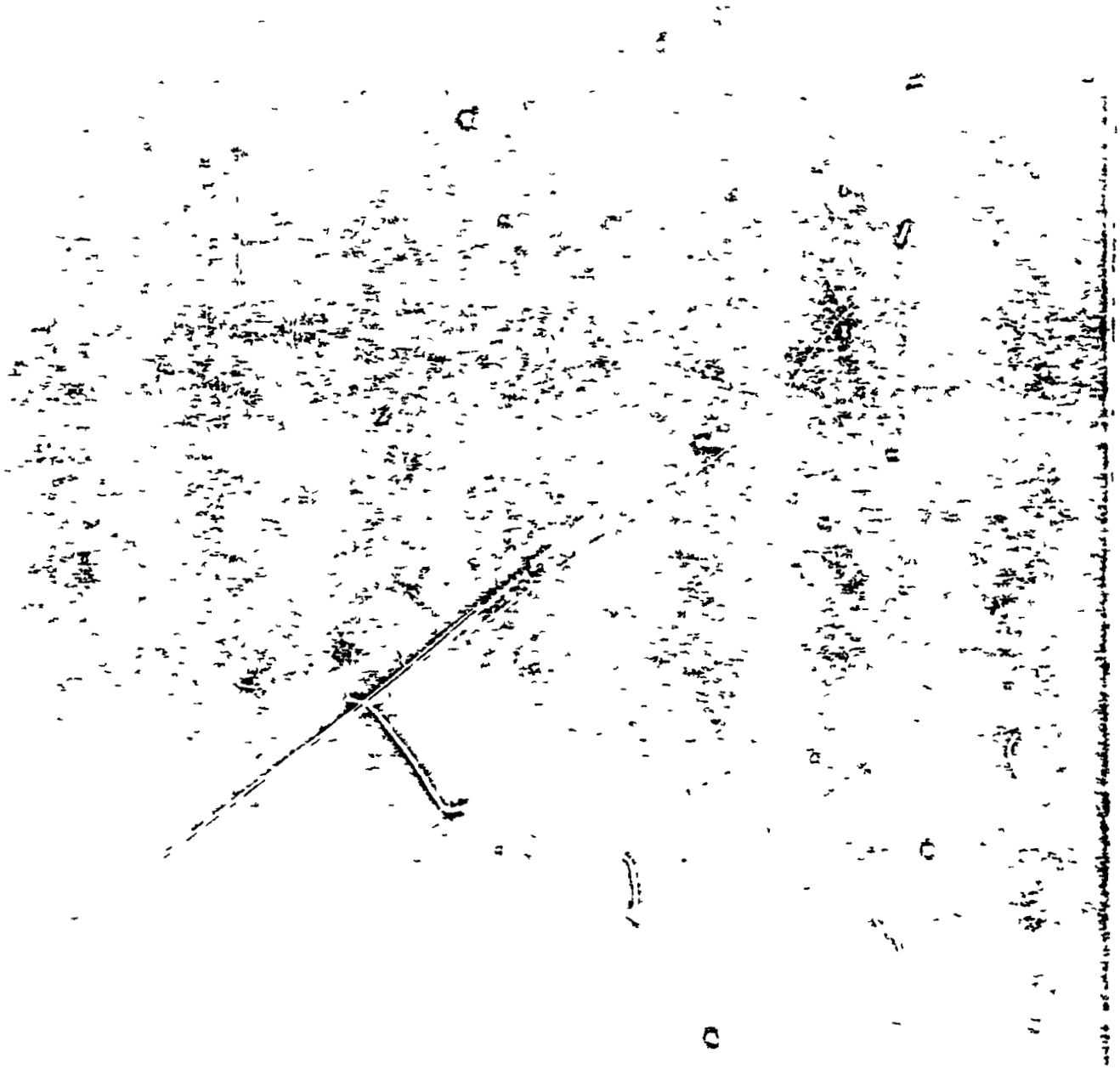
U S DEPARTMENT OF COMMERCE
National Technical Information Service

PB-255 572

PLUTONIUM LEVELS IN THE SEDIMENT OF AREA IMPOUNDMENTS ENVIRONS OF THE ROCKY FLATS PLUTONIUM PLANT - COLORADO

ENVIRONMENTAL PROTECTION AGENCY

FEBRUARY 1975



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7 AUTHOR(S) Milton W Lammering, Ph D	8 PERFORMING ORGANIZATION REPORT NO S&A/TIB-29
9 PERFORMING ORGANIZATION NAME AND ADDRESS Technical Investigations Branch Surveillance & Analysis Division U S Environmental Protection Agency, Region VIII Denver, Colorado 80203	10 PROGRAM ELEMENT NO 11 CONTRACT/GRANT NO
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15 SUPPLEMENTARY NOTES	

16 ABSTRACT

Plutonium concentrations in the bed sediment of reservoirs (Great Western Reservoir, Standley Lake, Cherry Creek Reservoir, Marston Lake, and Ralston Reservoir) in the environs of the Atomic Energy Commission Rocky Flats Plant were determined by dredge and core sampling. Great Western Reservoir and Standley Lake were sampled during October, 1973, the other three impoundments during April, 1974. The baseline level of plutonium-239 in bed sediment attributable to worldwide fallout was found to be ≤ 0.10 pCi/gram (dry weight). Correspondingly, the maximum concentrations in the top layer of sediment in Great Western Reservoir were approximately 4.0 pCi/gram (dry weight). The thickness of the layer of plutonium-contaminated sediment in the reservoir was 5 cm or more at most sampling stations. Through 1973, Great Western Reservoir received liquid wastes (plutonium-bearing) from the Rocky Flats Plant via the tributary stream, Walnut Creek.

17 KEY WORDS AND DOCUMENT ANALYSIS

a DESCRIPTORS	b IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Plutonium-239, bed sediment, AEC Rocky Flats Plant	Radiological contamination, sediment accumulation	

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INTPODUCTION

In September, 1973, the U S Environmental Protection Agency responded to a request from the Colorado Department of Health to assist in the investigation to verify the suspected release(s) of tritium in liquid wastes from the Rocky Flats Plant of the U S Atomic Energy Commission Although focused on the determination of tritium concentrations in area surface waters and the identification of the source(s) of such contamination, the overall scope of field investigation was expanded to include the monitoring of plutonium contamination of bottom sediment in Great Western Reservoir and Standley Lake (conducted during October, 1973) Both of these reservoirs lying short distances to the east of the plant receive drainage from the site Through 1973, Great Western Reservoir received treated liquid wastes (plutonium-bearing) from the Rocky Flats Plant via the tributary stream, Walnut Creek

Extensive sampling of bottom sediment in Great Western Reservoir was conducted previously by the Environmental Protection Agency during September, 1970 This sampling program also involved sediment sampling of an exploratory nature in Standley Lake As reported (1), the 1970 findings indicated the following

(1) Almost the entire bed of Great Western Reservoir was covered with sediment containing plutonium in excess of the estimated baseline concentration, $\leq$ 0 10 pCi/gram, attributable to worldwide fallout from nuclear weapons testing

(2) The possible existence of sectors of plutonium contamination in the deep-water area of Standley Lake attributable to "accidental" releases from the Rocky Flats Plant

As a follow-up to these findings, the subject sediment investigation was conducted to document changes in the plutonium contamination of the sediment bed of Great Western Reservoir over the intervening period of three years - September, 1970, to October, 1973 Additionally, extensive sampling of Standley Lake sediment was conducted to confirm the presence or absence of contaminated areas

To differentiate between sediment contamination caused by plutonium releases from the Rocky Flats Plant versus that resulting from worldwide fallout, sediment samples were collected on April 18, 1974, from Cherry Creek Reservoir, Marston Lake, and Ralston Reservoir Considering the predominant wind direction and the distances from the plant to the reservoirs, sediment contamination in these reservoirs attributable to gaseous effluents or windborne sources (contaminated soil) originating at the Rocky Flats Plant was considered negligible The three impoundments are not impacted by liquid effluents from the plant

SAMPLE COLLECTION AND ANALYSIS

PROCEDURES

Bottom sediment sampling stations in Great Western Reservoir and Standley Lake are shown in Figures I and II For these stations, the collection of dredge samples was predominent with this type collected at 37 of the 39 stations However, the majority of the stations (21 of 39) were also characterized by the collection of both core and dredge samples Dates of sediment collection for Great Western Reservoir and Standley Lake were October 18 and 25, respectively Personnel from the Colorado Department of Health assisted in the collection of samples from these two impoundments

Baseline sediment samples were collected from Cherry Creek Reservoir, Marston Lake, and Ralston Reservoir on April 18, 1974 Specific sampling locations are listed in Table I For these impoundments, sampling was limited to dredge samples.

Dredge samples were collected by the use of a Peterson dredge (without weights) To obtain the composite dredge sample for radiological analysis, the below procedure was followed

(1) The sediment sample contained in the jaws of the dredge was emptied into a pan. Caution was exercised to remove the collected sample as a layer with as little disturbance as possible The extent to which this was achieved successfully depended on the cohesiveness of the sample

(2) In the case of a fairly cohesive sample, the composite sample was prepared from aliquots obtained by scraping the sample surface with a hand trowel For non-cohesive samples which underwent significant mixing in the closed dredge as well as in the process of being removed from the dredge, the composite sample was prepared from aliquots judged to be representative of the overall sample texture That is, an attempt was made to duplicate the relative percentages of clay-like materials, silt, coarse materials (gravel, etc) and fines (sand)

Duplicate composite samples were prepared at all locations for analysis by the Colorado Department of Health and EPA

A Phleger Gravity Corer[a] was used to collect all but three core samples Shallow water depths at Stations 1, 2, and 4 in Great Western Reservoir prevented the use of the corer These samples were collected by manually pushing the plastic core tube into the sediment bed At all stations, field measurements of the depth of penetration of the corer and the corresponding length of the collected sample were taken to indicate the relative degree of compaction during the collection procedure Core samples were maintained in the frozen

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(a) Equipped with a 2' metal coring tube which housed a plastic core tube (1 5 inch inside diameter)

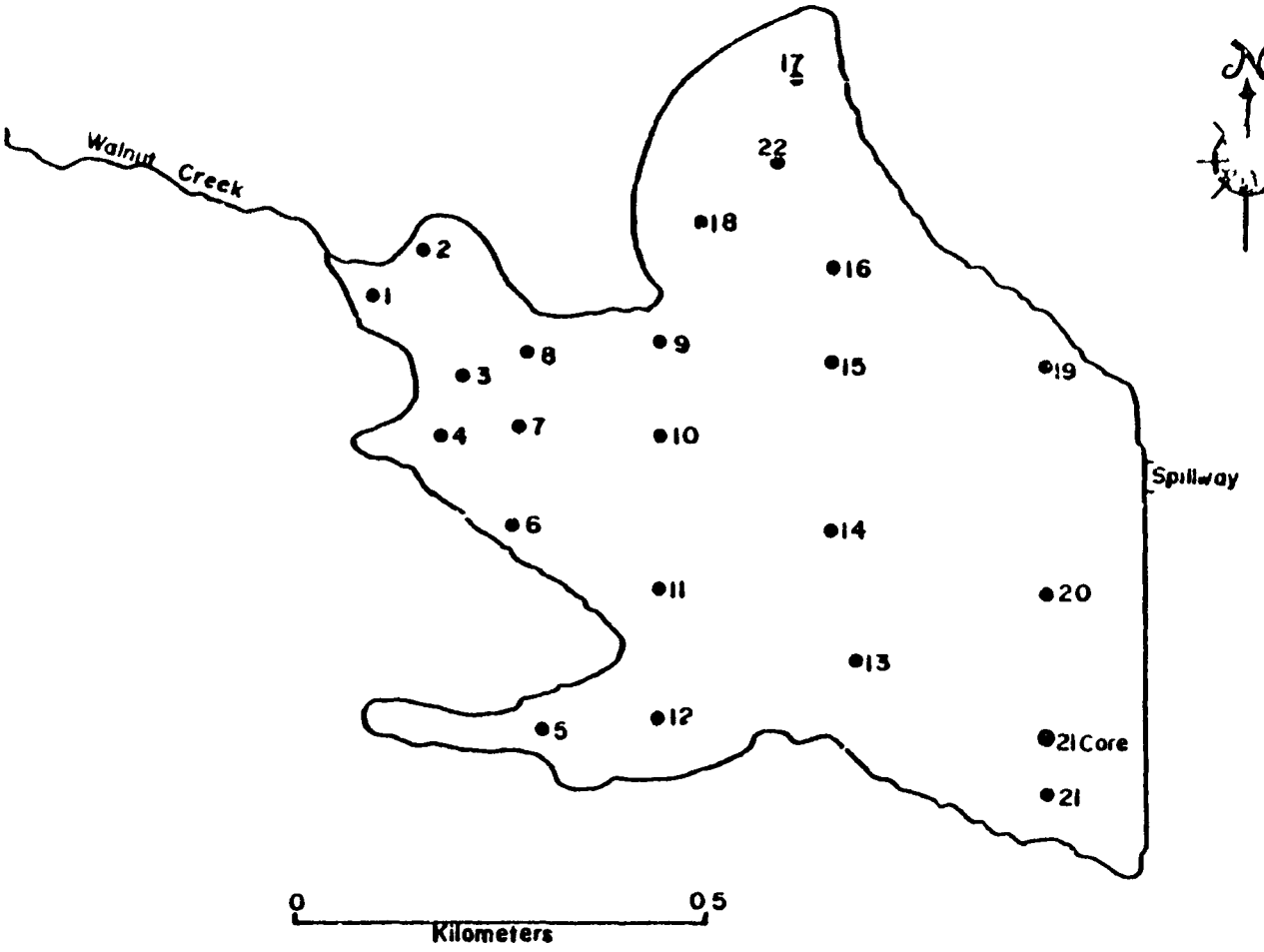


FIGURE I
BOTTOM SEDIMENT SAMPLING STATIONS
GREAT WESTERN RESERVOIR
OCTOBER 18, 1973

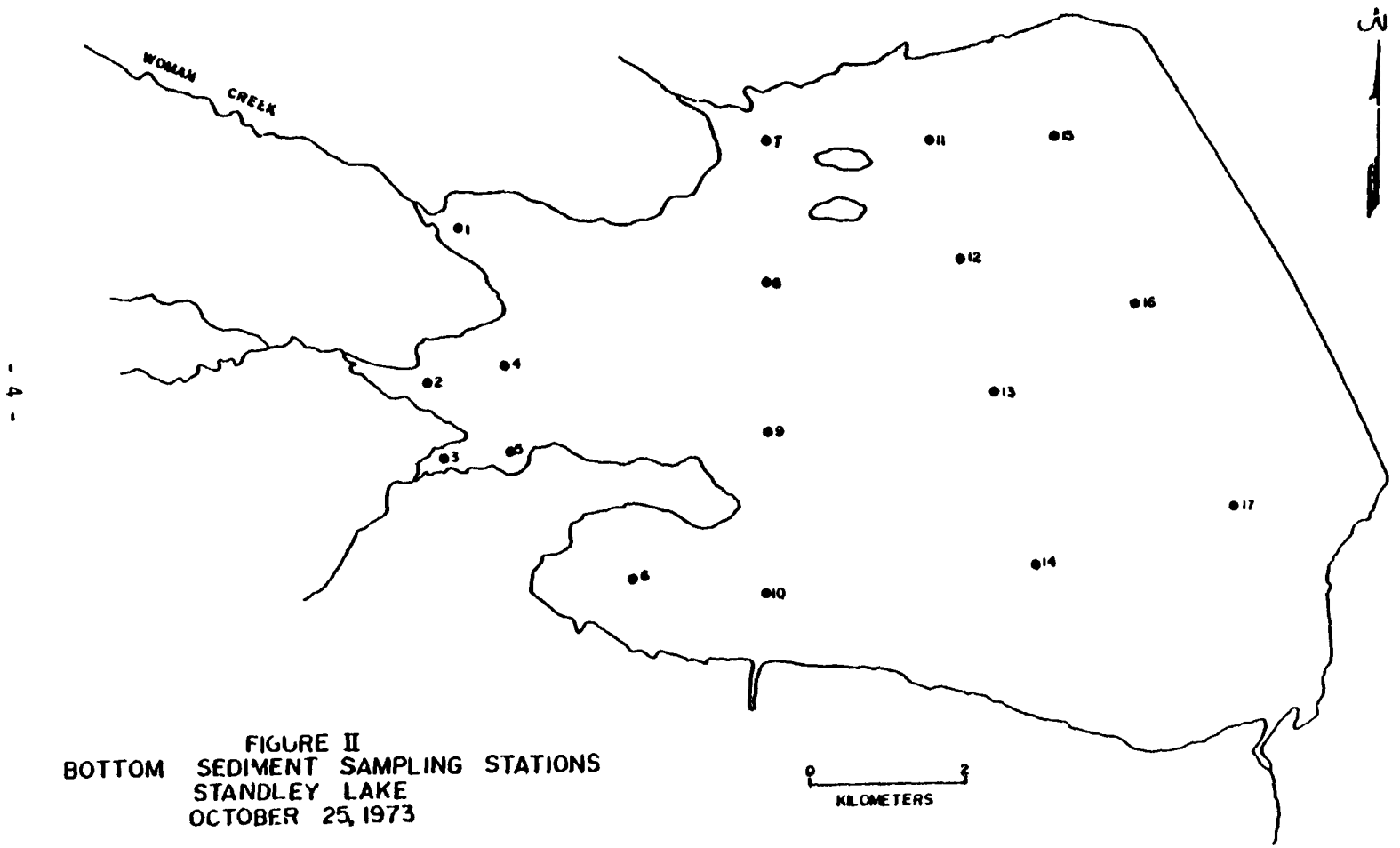


FIGURE II
BOTTOM SEDIMENT SAMPLING STATIONS
STANDLEY LAKE
OCTOBER 25, 1973

TABLE I

SEDIMENT SAMPLING STATIONS

CHERRY CREEK RESERVOIR, MARSTON LAKE, AND RALSTON RESERVOIR

Reservoir	Station Number	Location
Cherry Creek Reservoir (approximately 24 miles southeast of the Rocky Flats Plant)	CC-1	Approx 180 meters from the inlet
	CC-2	Approx 90 meters from the dam
Marston Lake (approximately 19 miles southeast of the Rocky Flats Plant)	M-1	Approx 45 meters from the inlet
	M-2	Approx 45 meters from the inlet
Ralston Reservoir (approximately 3 miles south of the Rocky Flats Plant)	R-1	Approx. 45 meters from the head end (mouth of Ralston Creek)
	R-2	Approx. 0.4 kilometers from the head end
	R-3	Approx 0 8 kilometers from the head end (equidistant between the head end and the dam)
	R-4	Approx. 0 4 kilometers from the dam
	R-5	Approx 45 meters from the dam

state during the interim period between collection and processing [a] A selected number of core sections were provided to Dow Chemical Company for their own analyses

All EPA samples were analyzed in the Office of Radiation Programs radiochemistry laboratory, National Environmental Research Center, Las Vegas, Nevada Dredge samples were analyzed for plutonium-238 and 239, cesium-137, beryllium, and potassium, selected samples also were analyzed for strontium-89 and 90 Core sections were analyzed for plutonium-239 with selected sections also analyzed for plutonium-238 and beryllium

(a) The process of "sectioning" each core sample initially involved thawing the sample and subsequently forcing the water out of the tube by pushing the sediment core upward with a metal plunger (core tube in a vertical position) The core sample was then sectioned by a stepwise process of pushing the sediment core upward and out of the tube, the exposed increment or step in each case being equal to the desired length of the core section. During the sectioning process, the core tube was held in a vertical position and the desired core section was pushed into an inverted glass jar held at the end of the tube A wide-blade knife was used to cut each section

RESULTS

Plutonium-239 results for core and dredge samples from the five impoundments - Cherry Creek Reservoir, Marston Lake, Ralston Reservoir, Standley Lake, and Great Western Reservoir - are presented in Tables II - IV. The plutonium-239 results for dredge samples from Great Western Reservoir and Standley Lake also are shown in Figures III and IV. Analytical data for other parameters (cesium-137, strontium-89 and 90, plutonium-238, beryllium and potassium) are presented in Appendix A.

Physical descriptions of the core samples, including compaction measurements, and corresponding photographs of the samples prior to "sectioning" are compiled in Appendix B. The compositions of dredge samples from Cherry Creek Reservoir, Marston Lake, and Ralston Reservoir are described in this same appendix.

TABLE II

PLUTONIUM CONCENTRATIONS IN SEDIMENT SAMPLES

RESERVOIRS IN THE DENVER METROPOLITAN AREA

Reservoir and Station	Approximate Water Depth (meters)	Plutonium-239 (pCi/gram)(a)
Cherry Creek Reservoir		
CC-1	4.5	<0.01
CC-2	6.0	<0.05
Marston Lake		
M-1	3.6	<0.02
M-2	4.5	0.13(b)
Ralston Reservoir		
R-1	2.4	<0.06
R-2	1.5	0.03
R-3	24	<0.03
R-4	33	0.04
R-5	33	0.06

(a) Dry weight basis
(b) Result verified by replicate analysis

TABLE II

PLUTONIUM CONCENTRATIONS IN SEDIMENT SAMPLES

STANDLEY LAKE

Station	Approximate Water Depth (meters)	Dredge Sample Plutonium-239 (pCi/gram)(a)	Core Sample	
			Core(b) Section (cm)	Plutonium-239 (pCi/gram)(a)
1	0.6	0.11	No Core	
2	0 8	0 04	No Core	
3	3.5	0 05	No Core	
4	1.0	0.04	0 - 2 54	<0 06
			7.62 - 10 2	<0 04
5	4.5	0.08	0 - 2 54	0 08
			10.2 - 12.7	<0.03
6	5 0	0 06	No Core	
7	9.5	0.15	0 - 2.54	<0 06
			2.54 - 5 08	<0 07
			14.0 - 16.5	<0.08
8	4.0	0.08	0 - 2 54	<0 09
			8 89 - 11 4	<0.07
9	2.5	<0 02	No Core	
10	1.0	0.08	No Core	
11	4.5	0 03	No Core	
12	13	0 10	0 - 2.54	0.10
			2 54 - 5.08	<0.08
			17 8 - 20.3	<0.03
13	6.0	0 03	0 - 2 54	<0.06
			7 62 - 10 2	<0 06

(a) Dry weight basis.
(b) The limits of the range are measurements in centimeters from the top surface of the core sample No correction was made for compaction during sample collection

TABLE III (continued)

Station	Approximate Water Depth (meters)	Dredge Sample Plutonium-239 (pCi/gram)[a]	Core Sample	
			Core[b] Section (cm)	Plutonium-239 (pCi/gram)[a]
14	6 0	0 08	No Core	
15	6 0	<0.06	No Core	
16	21	0.17	0 - 2 54	<0.10
			10 2 - 12 7	0.11
			15.2 - 17 8	0.07
			27.9 - 30 5	<0.04
17	9.0	<0 03	0 - 2 54	<0.16
			5.08 - 8 89	<0 04

TABLE IV

PLUTONIUM CONCENTRATIONS IN SEDIMENT SAMPLES

GREAT WESTERN RESERVOIR

Station	Approximate Water Depth (meters)	Dredge Sample Plutonium-239 (pCi/gram)[a]	Core Sample	
			Core[b] Section (cm)	Plutonium-239 (pCi/gram)[a]
1	6 5	2 0	0 - 2 54	1.0
			2 54 - 5.08	1.3
			14 0 - 16 5	0.10
2	0.6	0 61	0 - 2 54	0 54
			2.54 - 5 08	0.25
			6.35 - 8 89	<0.02
3	2.5	2.9	No Core	
4	0.5	0.46	0 - 3.49	0.25
			4.45 - 8.89	<0.02
5	1.0	0.18	0 - 2.54	0.57
			2.54 - 5.08	0 61
			7 62 - 10.2	<0.07
6	4.0	No Dredge Sample	0 - 2 54	0.47
			2.54 - 5 08	<0.07
			10.2 - 12 7	<0 07
7	4.0	2.5	0 - 2 54	3 8
			2 54 - 5 08	<0 06
			12 7 - 15.2	<0.03
8	3 5	1.4	0 - 2 54	2 6
			2 54 - 5 08	4 5
			17 8 - 20.3	<0 03
9	0.6	0.10	No Core	
10	5.5	2.3	No Core	
11	3.5	1 2	No Core	
12	5.5	<0.06	No Core	

(a) Dry weight basis
(b) The limits of the range are measurements in centimeters from the top surface of the core sample No correction was made for compaction during sample collection.

TABLE IV (continued)

Station	Approximate water Depth (meters)	Dredge Sample Plutonium-239 (pCi/gram)(a)	Core Sample	
			Core(b) Section (cm)	Plutonium-239 (pCi/gram)(a)
13	3 5	0.44	0 - 2 54	0 34
			8 89 - 11 4	<0 06
14	9.5	4.1	0 - 2 54	2.6
			2.54 - 5 08	2 2
			17 8 - 20 3	<0 08
15	9.3	2 5	0 - 2 54	0 30
			5 08 - 7 03	<0.07
16	4 5	0.62	0 - 3.81	1.3
			3 81 - 6 35	0 35
			11.4 - 14.0	<0 08
17	2.3	0.68	No Core	
18	0.8	0 19	No Core	
19	9.0	1.8	0 - 2.54	3.9
			2.54 - 5 08	1 9
			12.7 - 15.2	<0 04
20	12	3.8	0 - 1.91	3 8
			1.91 - 3.18	4 4
			13.7 - 16 2	<0.04
21(c)	7.3	0.29	0 - 2 54	2.2
			2.54 - 5 08	0 71
			17 1 - 19 7	<0 04
22	No Measurement	No Dredge Sample	0 - 2.54	0 10
			5 08 - 7 62	<0.10
			12.7 - 15 2	<0 04

(c) As shown in Figure I, the core and dredge samples for this sampling station designation were not collected in the same approximate location The dredge sample was collected more inshore in shallow water

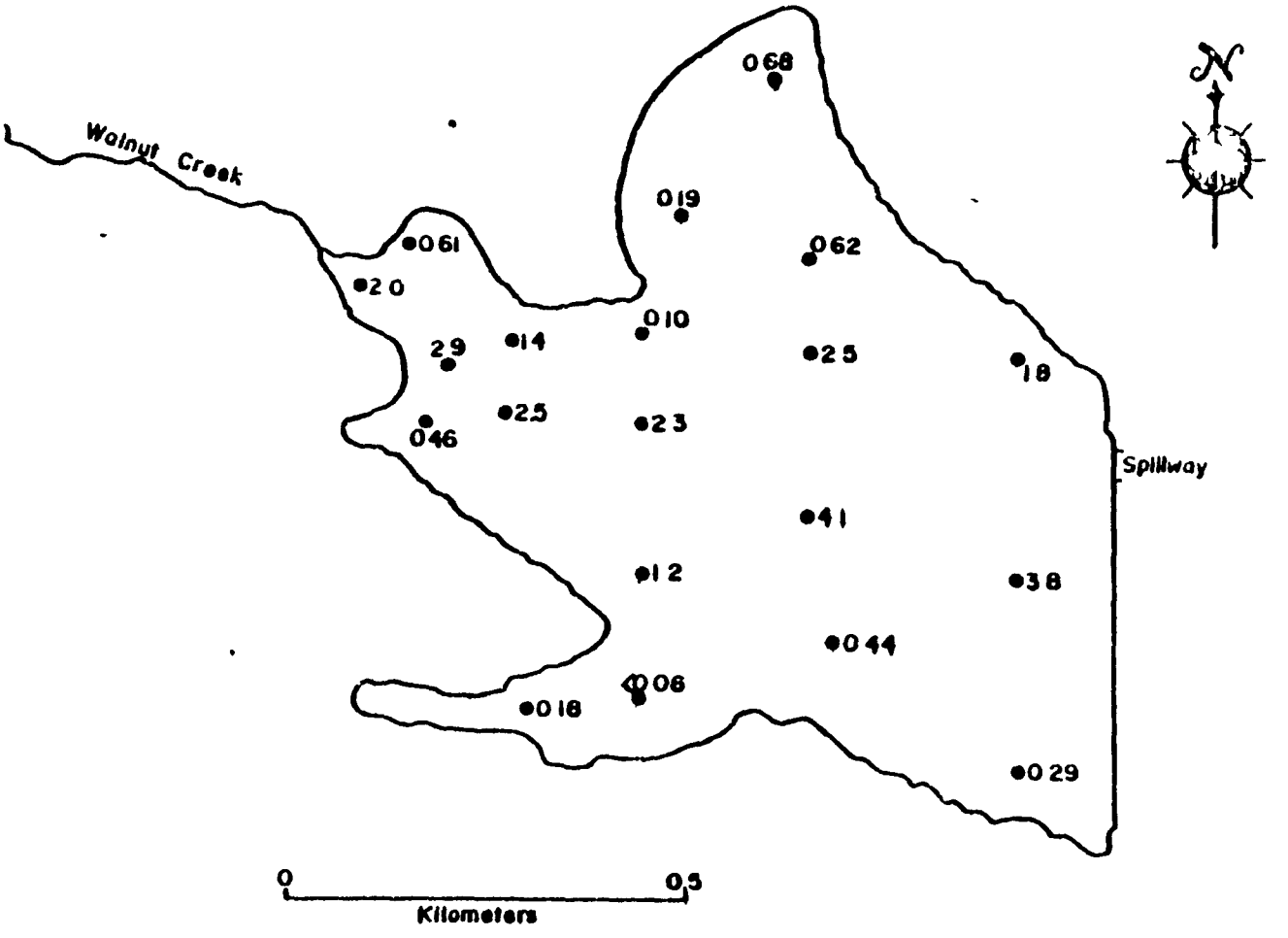
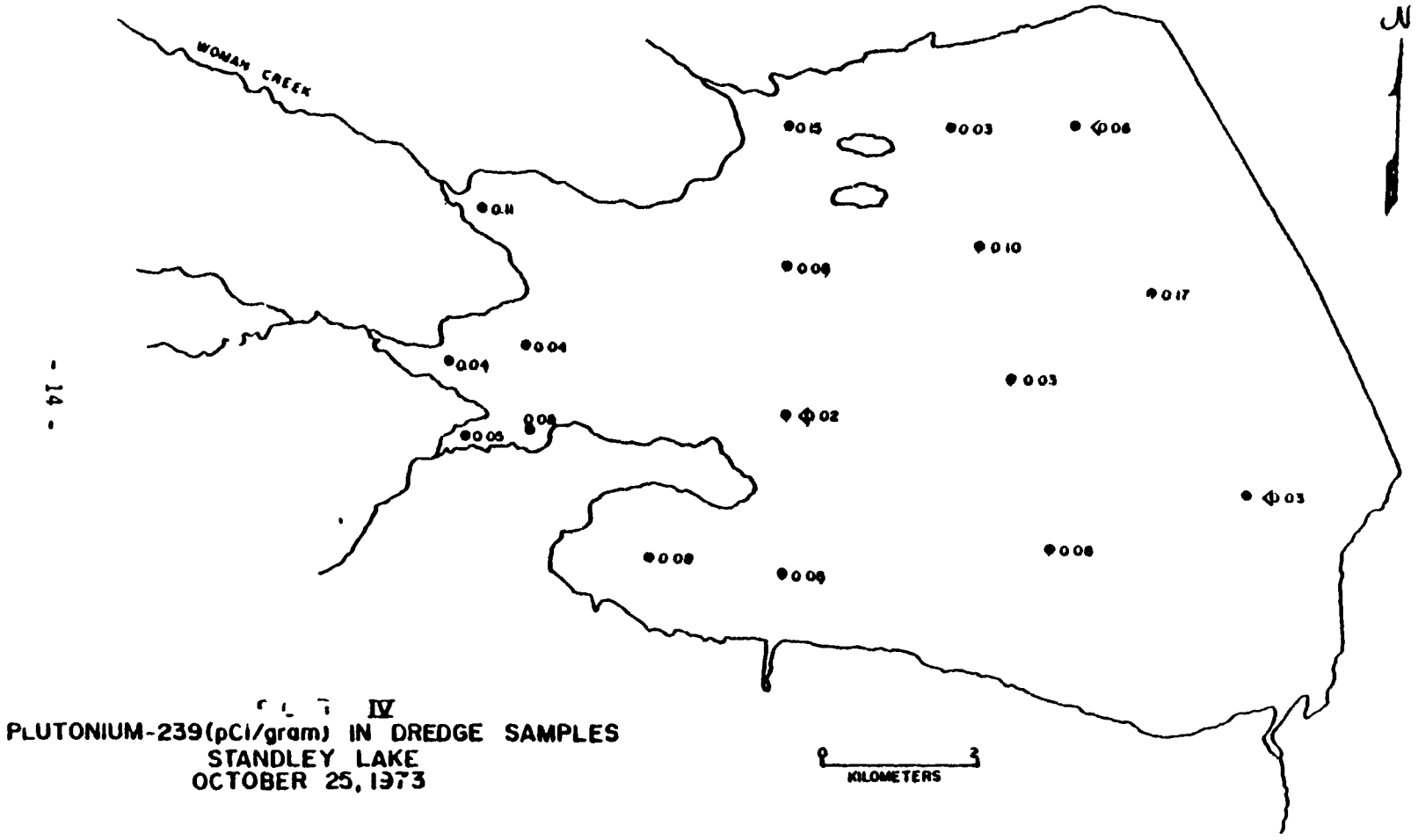


FIGURE III
PLUTONIUM-239 (pCi/gram) IN DREDGE SAMPLES
GREAT WESTERN RESERVOIR
OCTOBER 18, 1973



- 14 -

IV
PLUTONIUM-239(pCi/gram) IN DREDGE SAMPLES
STANDLEY LAKE
OCTOBER 25, 1973

DISCUSSION

With one exception (Station M-2, Marston Lake), dredge samples from Cherry Creek Reservoir, Marston Lake, and Ralston Reservoir contained plutonium-239 at concentrations substantially below 0.10 pCi/gram (Table II). This confirmed previous findings leading to the conclusion that the baseline level of plutonium-239 contamination in the bed sediment of area surface waters is typically less than 0.10 pCi/gram. The sediment concentration of 0.13 pCi/gram obtained for Station M-2 on Marston Lake was considered to be more of a spurious result than a real concentration. The factors which could have contributed to a "high" result were many. However, since the composite sample was analyzed in duplicate, the reason was more probably one of sample collection and preparation as opposed to analytical inaccuracies. That is, the composite sample prepared from the Petersen dredge sample may have been biased in the percentage of "fines" and somewhat unrepresentative of actual bed conditions.

Taken collectively, the plutonium-239 results for sediment samples collected from Standley Lake did not indicate any discernible contamination attributable to the Rocky Flats Plant (Table III). Only the dredge samples from Stations 7 and 16 showed concentrations slightly in excess of the established baseline value (0.15 and 0.17 pCi/gram versus <0.10 pCi/gram). However, core samples from these two locations were characterized by baseline levels in all analyzed sections. Accordingly, baseline conditions were concluded to be existent at these two locations since the core samples were more representative of the undisturbed sediment bed (a). Analysis of core sections from all other sampling locations also showed baseline concentrations of plutonium-239. Compared to the findings of the 1970 study, the indication of possible contamination to a depth of approximately 30 cm (compacted) in the deep water area near the dam was not verified.

Plutonium-239 results for dredge samples and the top sections (≤2.54 cm) of the core samples showed contamination attributable to liquid wastes from the Rocky Flats Plant over almost the entire bed of Great Western Reservoir (Table IV). Consistent with the 1970 study, the zone or area of highest contamination was the central section of the reservoir (inlet to dam). Areas of minimum impact(b) were the south arm (Stations 5 and 12), the shallow-water, shoreline area between the south arm and the dam (Station 21-dredge), and the western portion of the north arm (Stations 9, 18, and 22). The major differences between the 1970 and 1973 studies were the following.

(1) Over the three year period between sediment sampling efforts, the plutonium-239 concentrations in the upper sediment layer increased signi-

---

(a) In comparison to a dredge sample, the core sample represents a relatively undisturbed segment of the sediment bed. There is little mixing of sediment particles in a vertical direction although significant compaction of unconsolidated material does occur.

(b) Plutonium-239 concentrations less than 0.30 pCi/gram

ficantly Whereas the maximum concentration observed in 1970 was 0 86 pCi/gram, the October, 1973, study showed eleven (11) stations characterized by plutonium-239 concentrations greater than 1 0 pCi/gram The maximum concentration was 4 1 pCi/gram (Station 14)

(2) In contrast to the 1970 observation of maximum concentrations occurring in the reservoir inlet area (adjacent to the mouth of Walnut Creek) the 1973 study showed maximum concentrations in the deep-water area of the reservoir (Stations 14 and 20).

The core samples supported the previous finding of plutonium contamination extending to depths of 5 cm or more (compacted) at most locations (Table IV) Generalized, the typical concentration-sediment depth (thickness) profile was one of decreasing concentrations with increased sediment thickness.

Comparing the Great Western Reservoir plutonium-239 results for dredge samples with those for corresponding top sections of core samples showed no better than "order-of-magnitude" agreement at each station. The reasons for the lack of relatively close agreement in terms of absolute concentration values are considered to be physical differences introduced by sampling techniques and procedures. As noted in a previous footnote, the dredge and core collection procedures produce disturbed and undisturbed samples, respectively The other factor of importance was the field procedure involving the collection of core samples as a separate activity following the completion of dredge sample collection. This involved revisiting each sampling site a second time. Since the location of each sampling station was determined by "eye" from references to unique shoreline features, the sampling stations shown in Figure I represent general areas of limited size and not specific points Hence, the dredge and core samples for any given sampling location represented samples collected from only the same general area and were expected to show variations in concentrations.

The cesium-137, strontium-89/90, plutonium-238, and beryllium data for core and dredge samples from Great Western Reservoir and Standley Lake did not indicate significant differences within a given impoundment or between the two impoundments (Appendix A).

SUMMARY

The October, 1973, sediment study of Standley Lake and Great western Reservoir and the April, 1974, sediment study of Cherry Creek Reservoir, Marston Lake, and Ralston Reservoir produced the following significant findings.

(1) In the environs of the Rocky Flats Plant, the baseline level of plutonium-239 in the bed sediment of impoundments is $\leq$ 0.10 pCi/gram (dry weight).

(2) Sediment throughout Standley Lake was found to contain plutonium-239 at baseline levels.

(3) Plutonium contaminated sediment attributable to the routine discharge of plutonium-bearing liquid wastes from the Rocky Flats Plant occurred throughout Great Western Reservoir. Maximum concentrations in the top layer of sediment (2.54 cm - compacted) were approximately 40X the baseline concentration; i.e. approximately 4.0 pCi/gram (dry weight). The thickness of the layer of plutonium-contaminated sediment was 5 cm or more at most sampling stations.

ROCKY FLATS Environmental MASTER FILE

ENVIRONMENTAL SCIENCES AND WASTE CONTROL

SERVICE REPORT

Report No 317-74-127

Title SURVEY OF RESERVOIR SEDIMENTS

Work Requested By M. A. Thompson

Date Requested June 1974

Work Performed By K. K. Kunert and G. J. Werkema

Manhours 80

Date Work Started November 1973

Date Work Completed August 1974

Date This Report. August 23, 1974

Report Written By K. K. Kunert and G. J. Werkema

Distribution

R. R Gunning
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~~Coring~~
~~Cesium~~
Plutonium
Water
~~Sampling~~
~~Environment~~

Kunert, K.K
Werkema, G.J

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INTRODUCTION

Core and dredge samples were collected from the bottoms of Great Western Reservoir and Standley Lake during October 1973 The sampling program was conducted jointly by the United States Environmental Protection Agency (USEPA) and the Colorado Department of Health[1] to assess selected radionuclide concentrations in the reservoir bottoms.

Core samples were collected in 1-inch diameter pipes which were sectioned in 1-inch horizons. Sediment (dredge) samples were collected using a Petersen dredge. Sample locations are shown in Figures 1 and 7.

The USEPA requested that Rocky Flats Plant participate in the analysis of approximately one-third of the core samples. The Rocky Flats portion of the samples were analyzed at Battelle-Pacific Northwest Laboratory and Lawrence Livermore Laboratory. The remaining samples were analyzed by the USEPA at the National Environmental Research Center-Las Vegas. The most complete data were obtained for plutonium and cesium-137.

Analytical data were exchanged with USEPA in June 1974. The following discussion is based on a graphical synthesis of the data, including horizontal dispersions at several depths, and vertical profiles at some stations.

DISCUSSION

Tables I and II show the concentrations of Pu 239-240 and Pu 238 in the dredge samples and the core samples and the Cs 137 concentrations in the dredge samples in picocuries per gram (pCi/g). From these data contour drawings (Figures 2-6 and 7-9) were made of the Pu 239-240 and Cs 137 concentrations in the dredge samples and the Pu 239-240 concentrations for different depths of the core samples. Graphs were plotted of the concentration versus depth for the Pu 239-240 core samples (Figures 10-18).

The following conclusions are based on these graphical distributions and tables.

---

[1] Milton W Lammering, USEPA, REGION VIII
J. B. Baird, Colorado Department of Health

A. Great Western Reservoir

1. Highest concentrations of Pu 239-240 are found in the low areas of the reservoir and along the dam (Figures 2, 3, and 4)

2. Cs 137 concentrations are highest in the low area by the dam (Figure 6)

3 Core samples were not analyzed at every depth, so plots of concentration versus depth are not complete. In most cases the highest concentrations of Pu 239-240 were in the 0-1" level. At four sample locations the 1-2" level was higher than the 0-1" level. These locations are 1, 5, 8 and 20 (Figures 10, 12, 13, and 17)

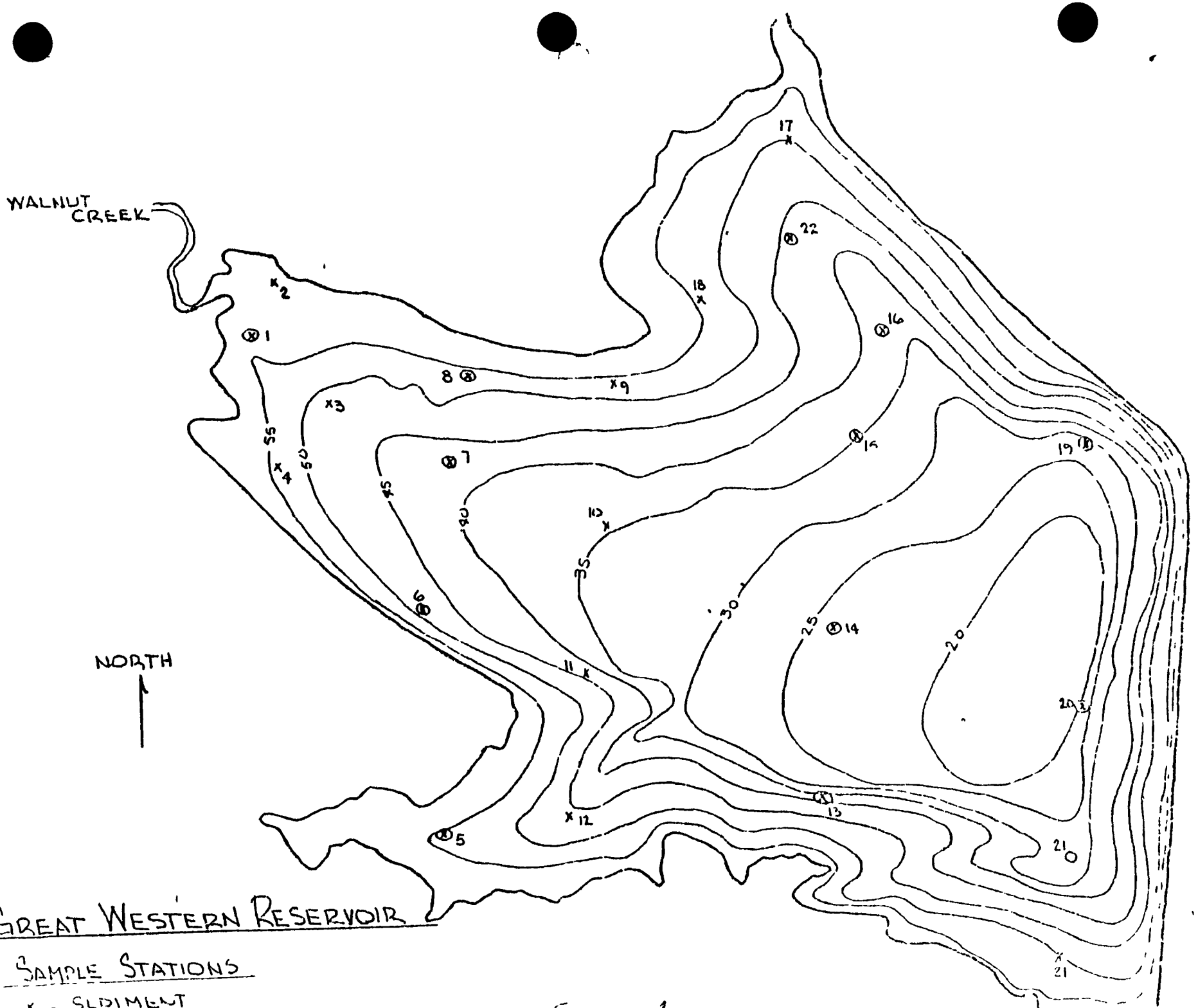
4 Dredge samples 1, 12, and 21 (Table I) show a difference between the EPA's results and Rocky Flats' results, the EPA's being lower. In two cases, points 14 and 19, EPA and Rocky Flats results are close.

B. Standley Lake

1. Highest Pu 239-240 concentrations are found by the dam and by the island (Figure 8). These concentrations are lower than those for Great Western (0 1 for Standley and 4.1 for Great Western).

2. The Cs 137 concentrations in Standley Lake are about the same as in Great Western Reservoir (2.4 for Standley and 2 1 for Great Western). Cs 137 is also concentrated at the dam and around the island (Figure 9)

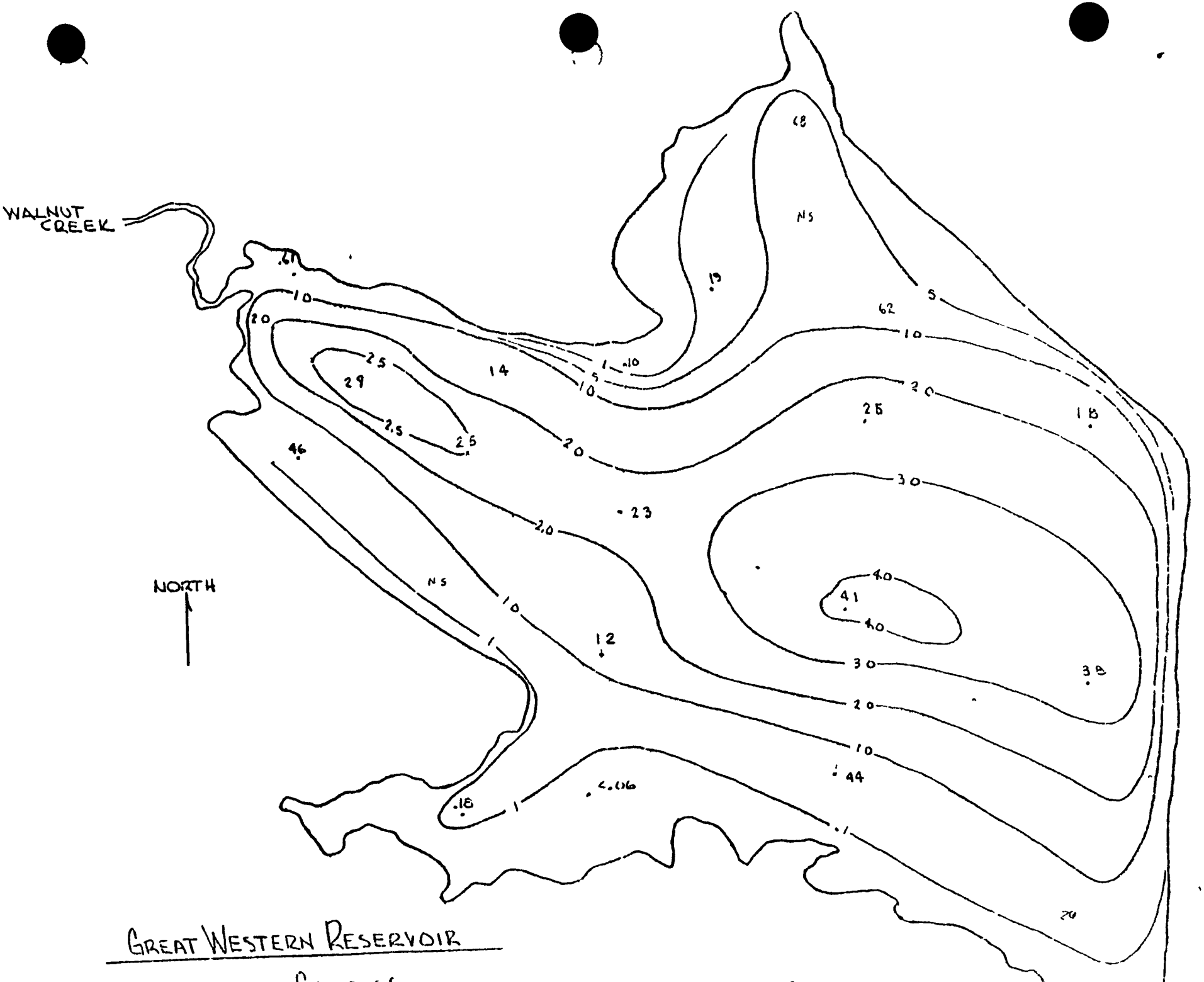
3. Sample points 2, 5, 7, 10, 15 and 17 show differences between EPA and Rocky Flats results, Rocky Flats results being higher (Table II).



GREAT WESTERN RESERVOIR

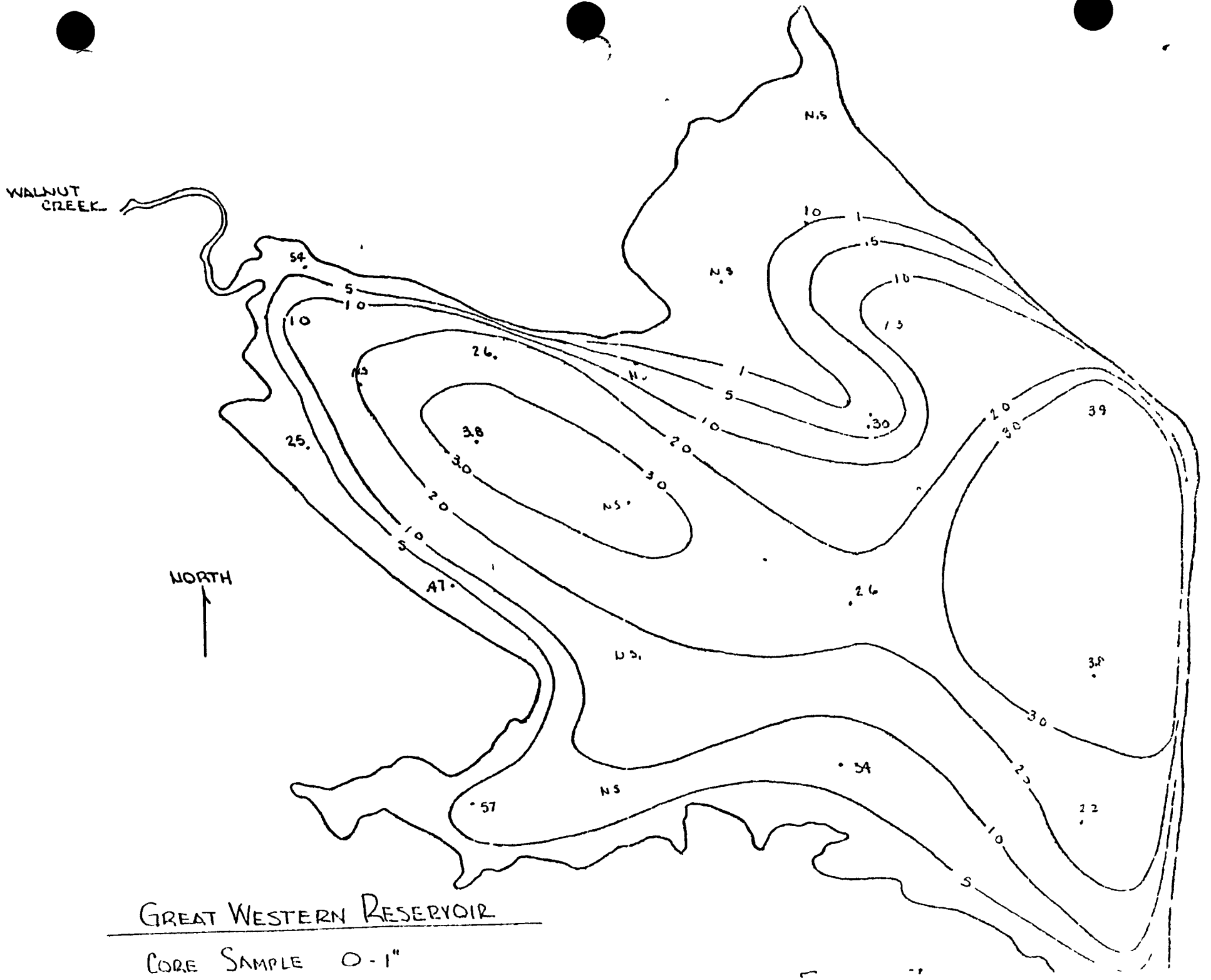
SAMPLE STATIONS

x - SEDIMENT



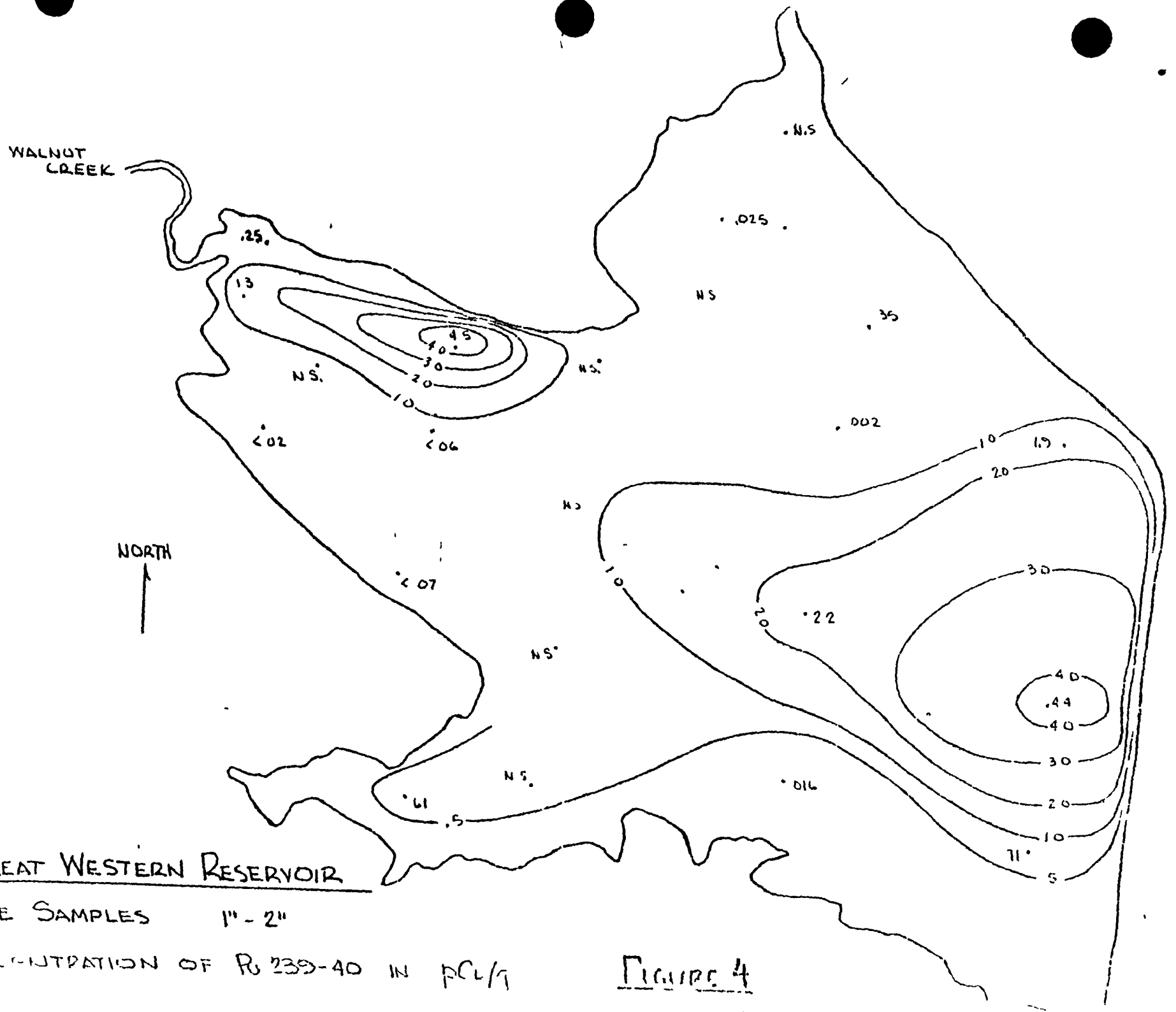
GREAT WESTERN RESERVOIR

DREDGE SAMPLES



GREAT WESTERN RESERVOIR

CORE SAMPLE 0-1"

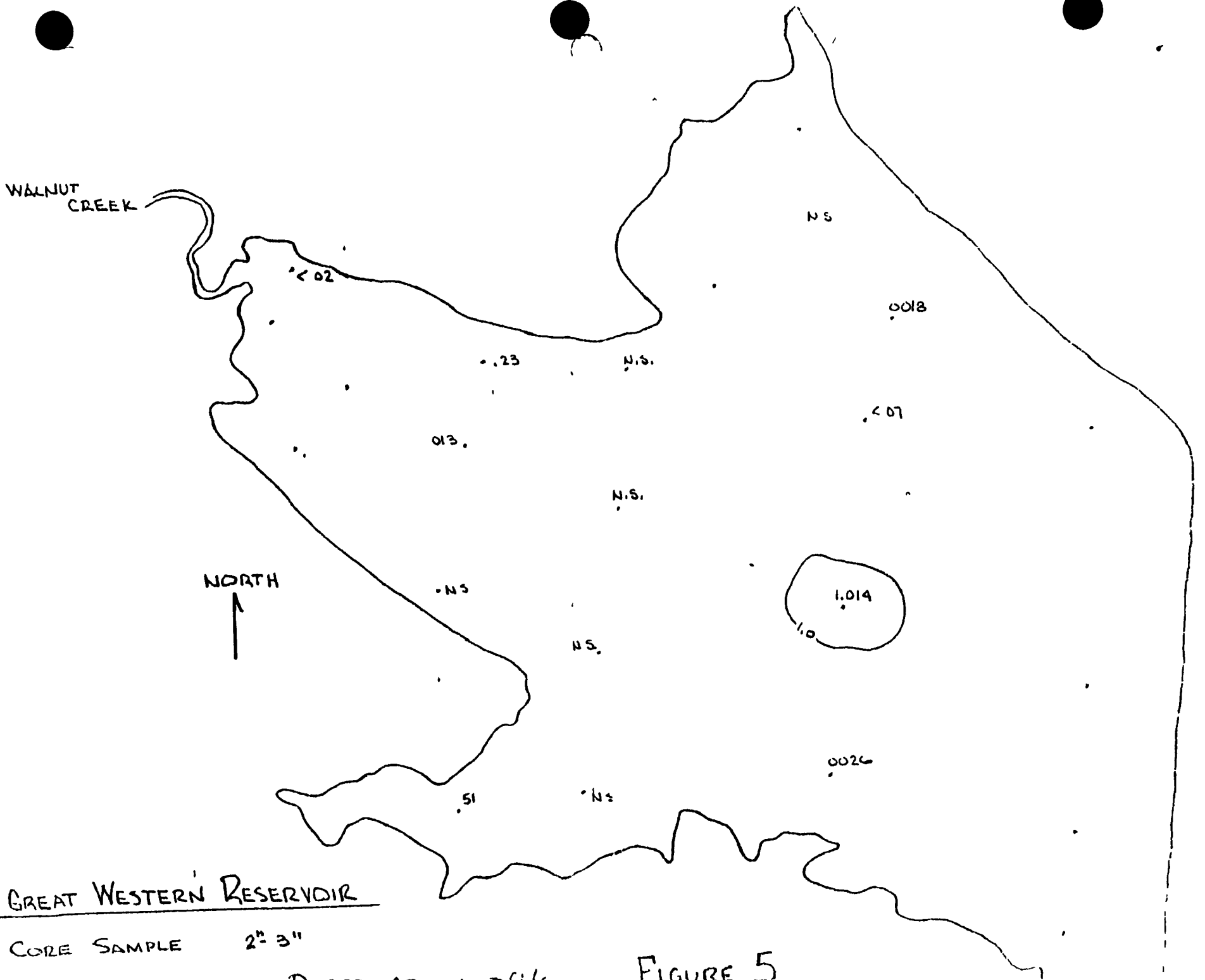


GREAT WESTERN RESERVOIR

CORE SAMPLES 1" - 2"

CONCENTRATION OF Pu 239-40 IN pCi/g

FIGURE 4

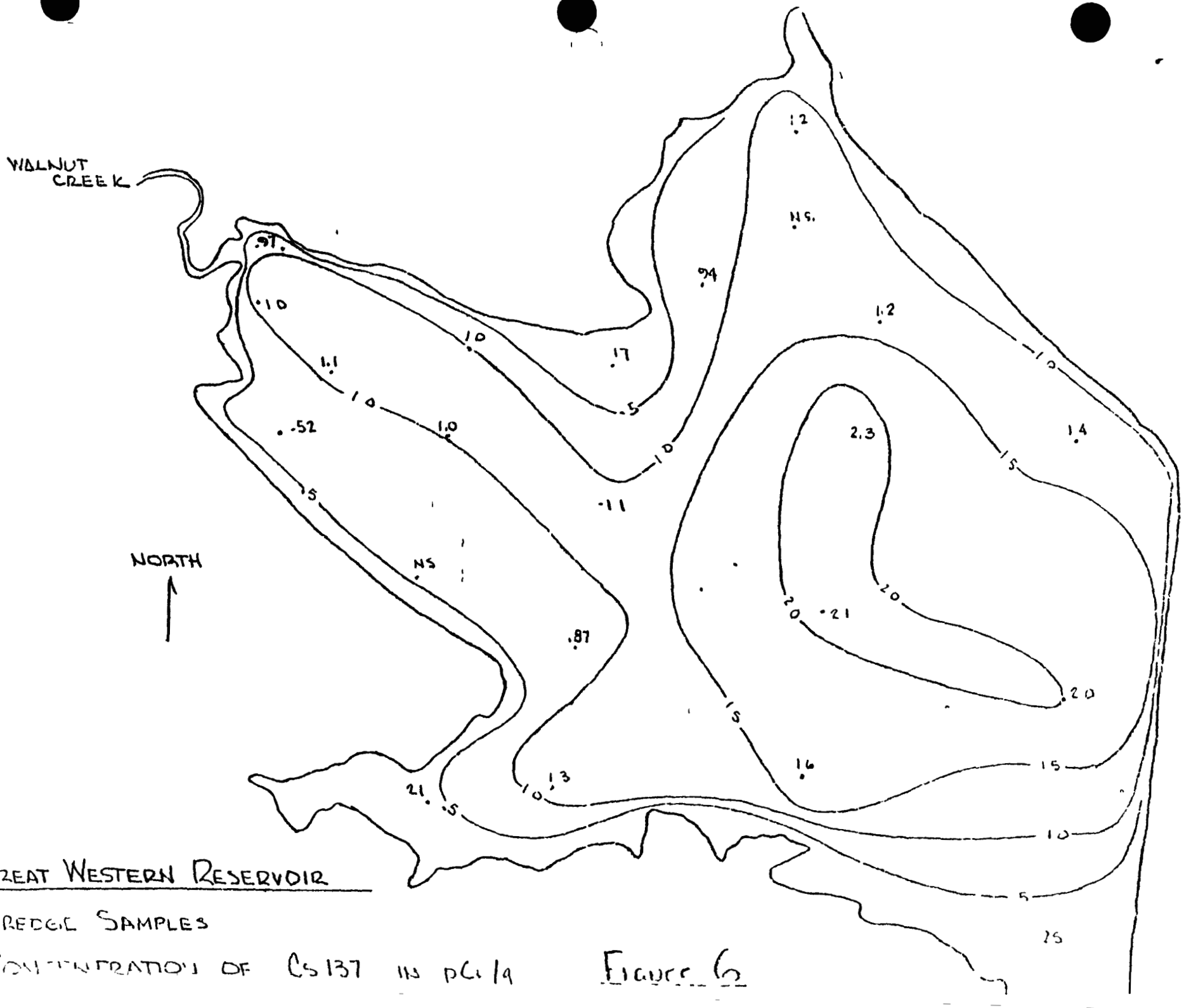


GREAT WESTERN RESERVOIR

CORE SAMPLE 2"- 3"

CONCENTRATION OF Pu 239-40 IN pCi/g

FIGURE 5

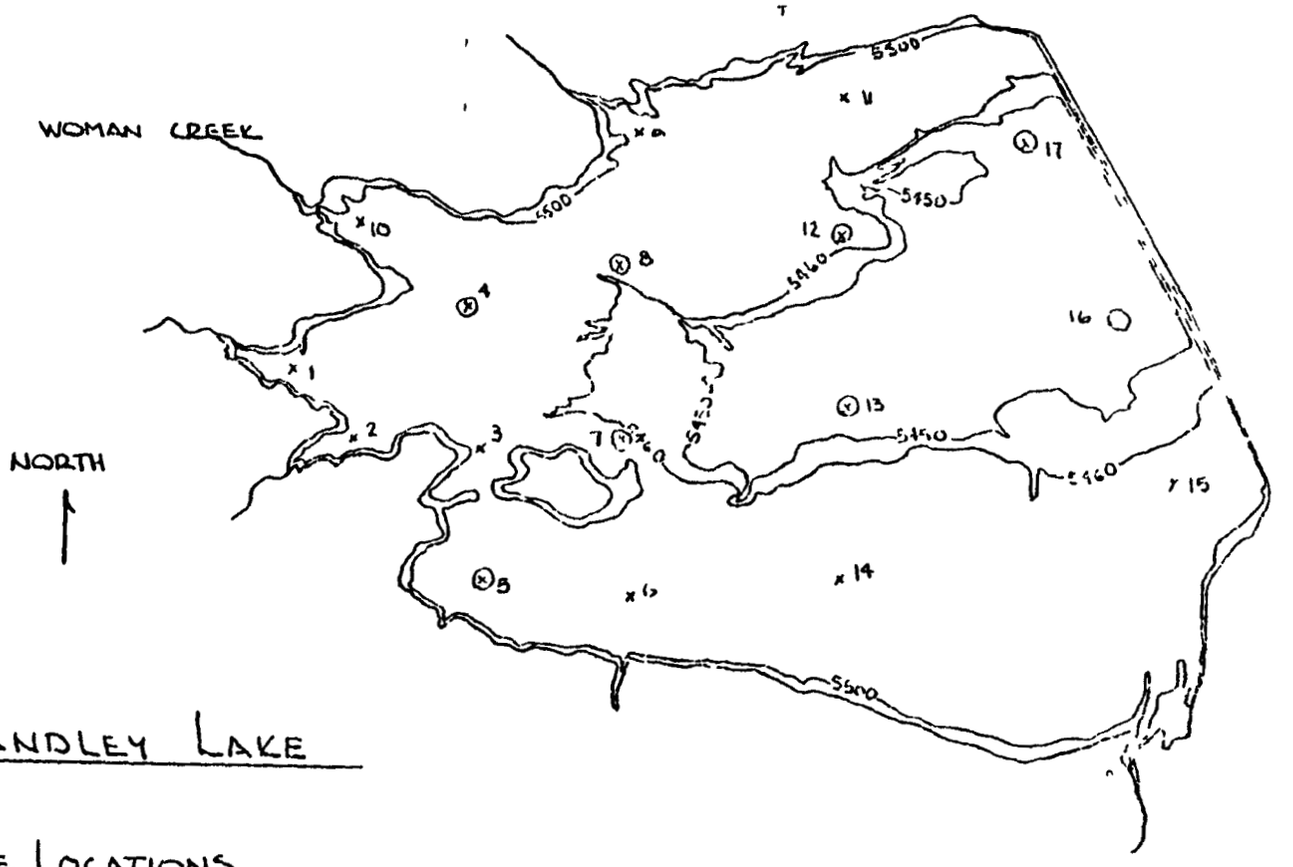


GREAT WESTERN RESERVOIR

DREDGE SAMPLES

CONCENTRATION OF Cs 137 IN pCi/g

FIGURE 6



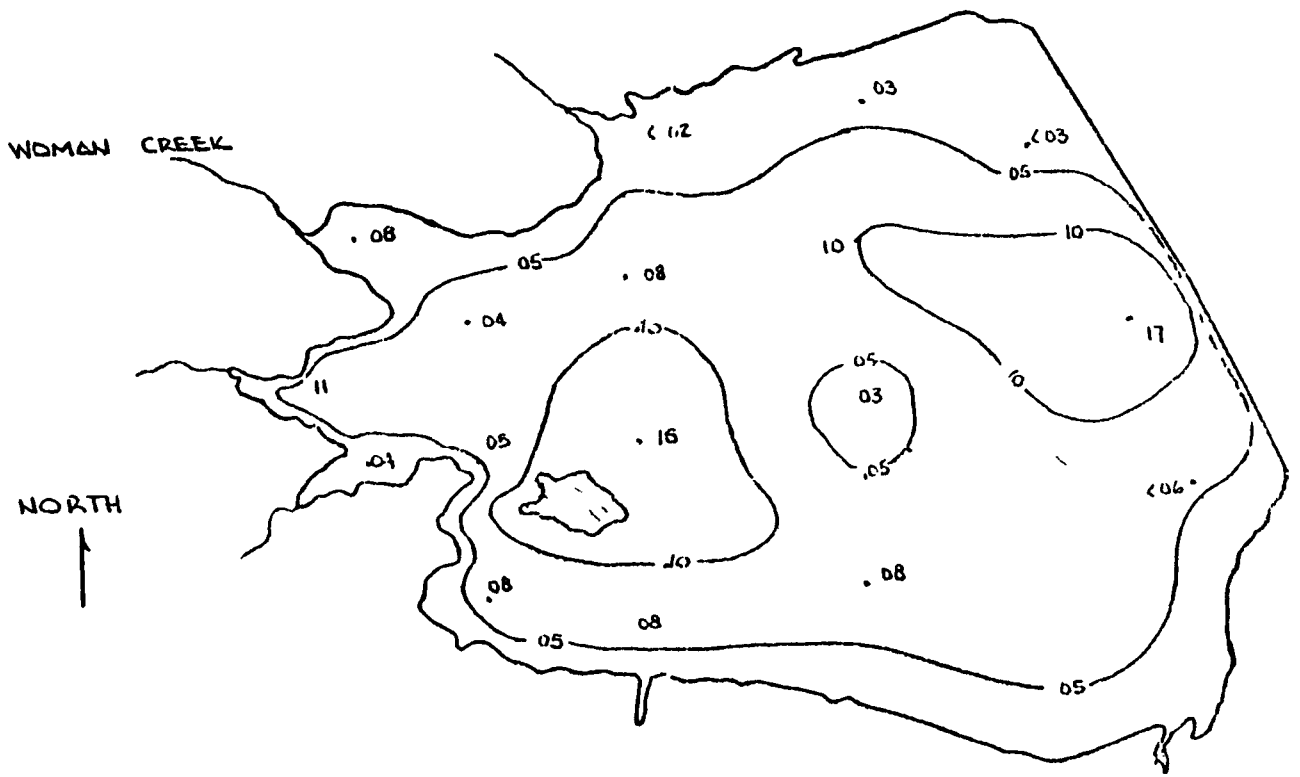
STANDLEY LAKE

SAMPLE LOCATIONS

x - SEDIMENT

⊗ - SEDIMENT AND CORE

FIGURE 7

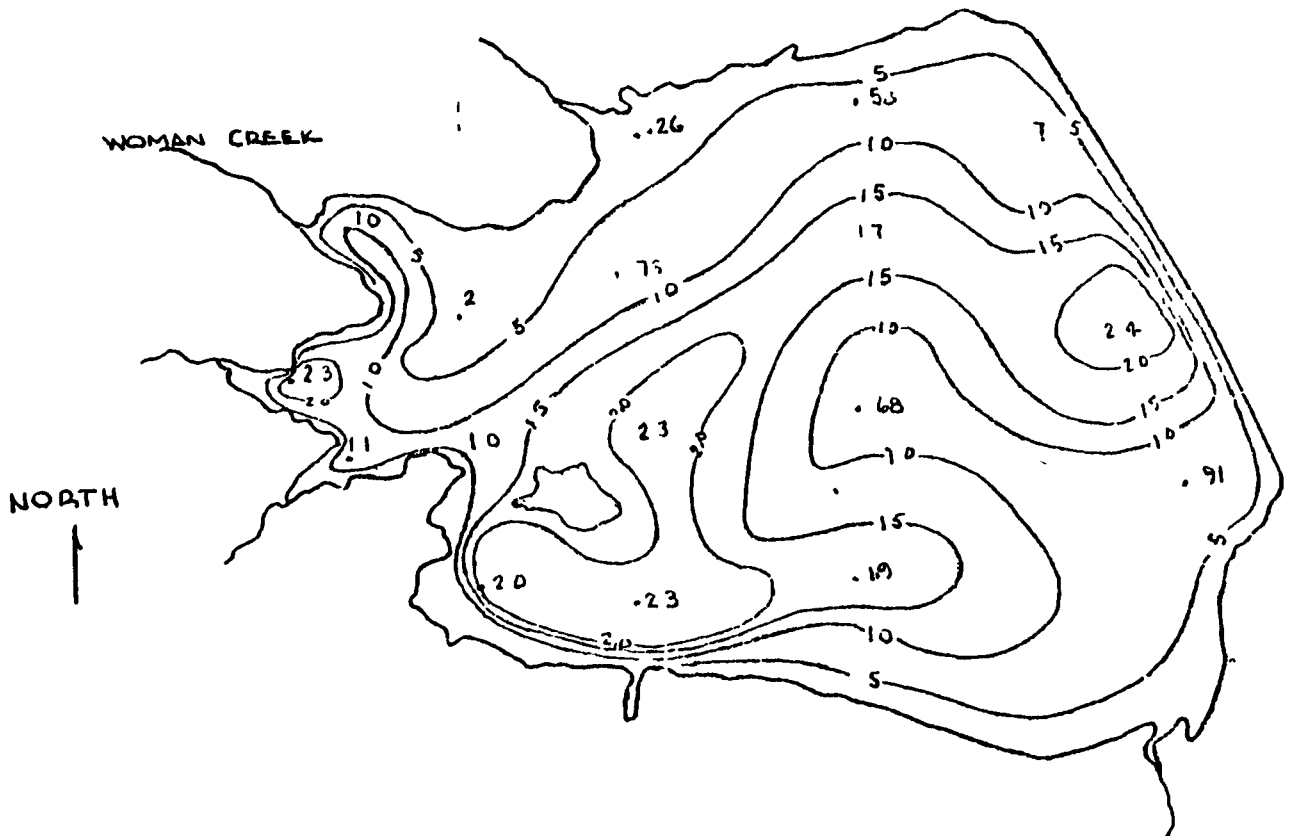


STANDLEY LAKE

SEDIMENT SAMPLES

CONCENTRATION OF Pu239-40 IN pCi/g

FIGURE 8



STANDLEY LAKE

SEDIMENT SAMPLES

CONCENTRATION OF Cs 137 IN pCi/g FIGURE 7

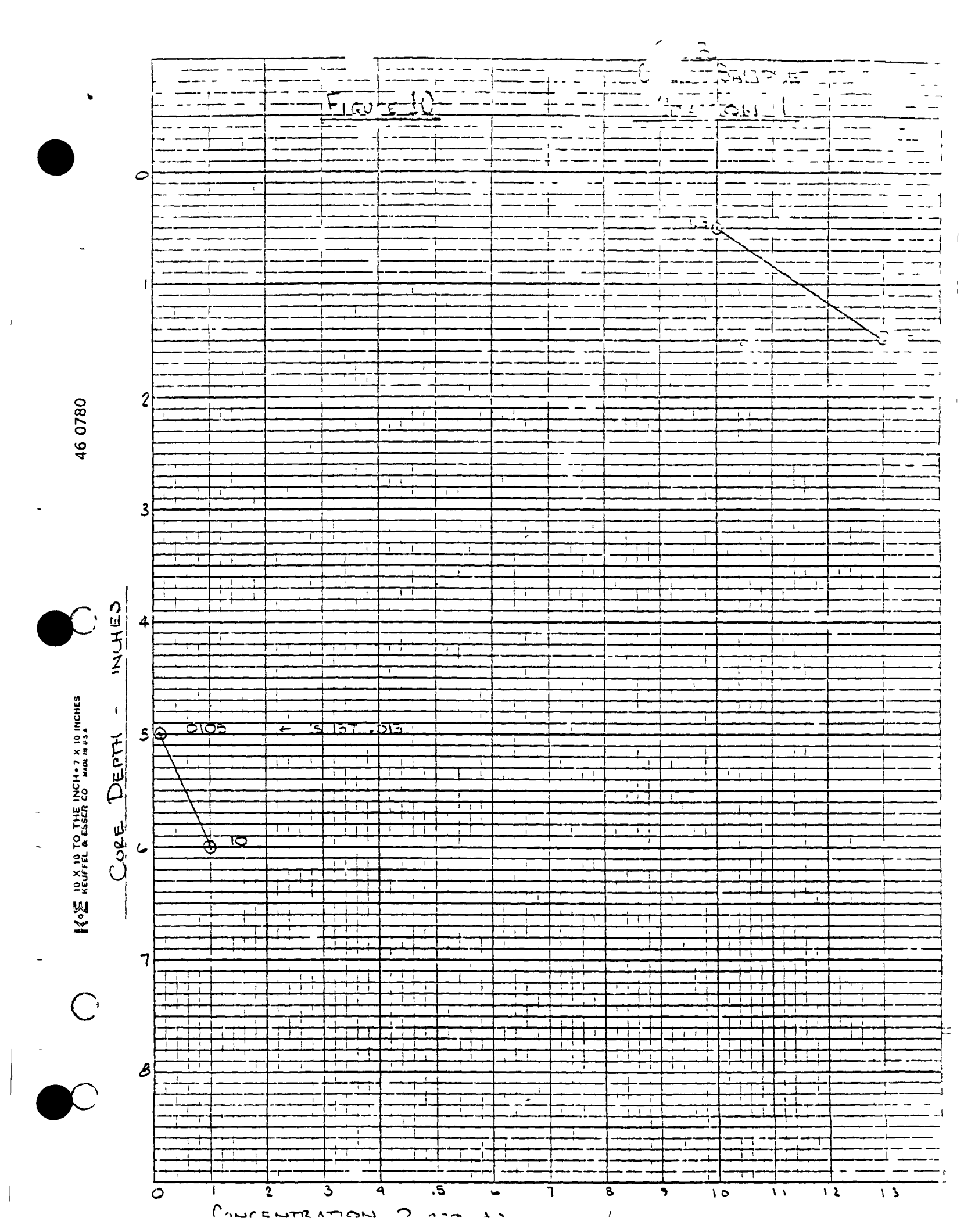
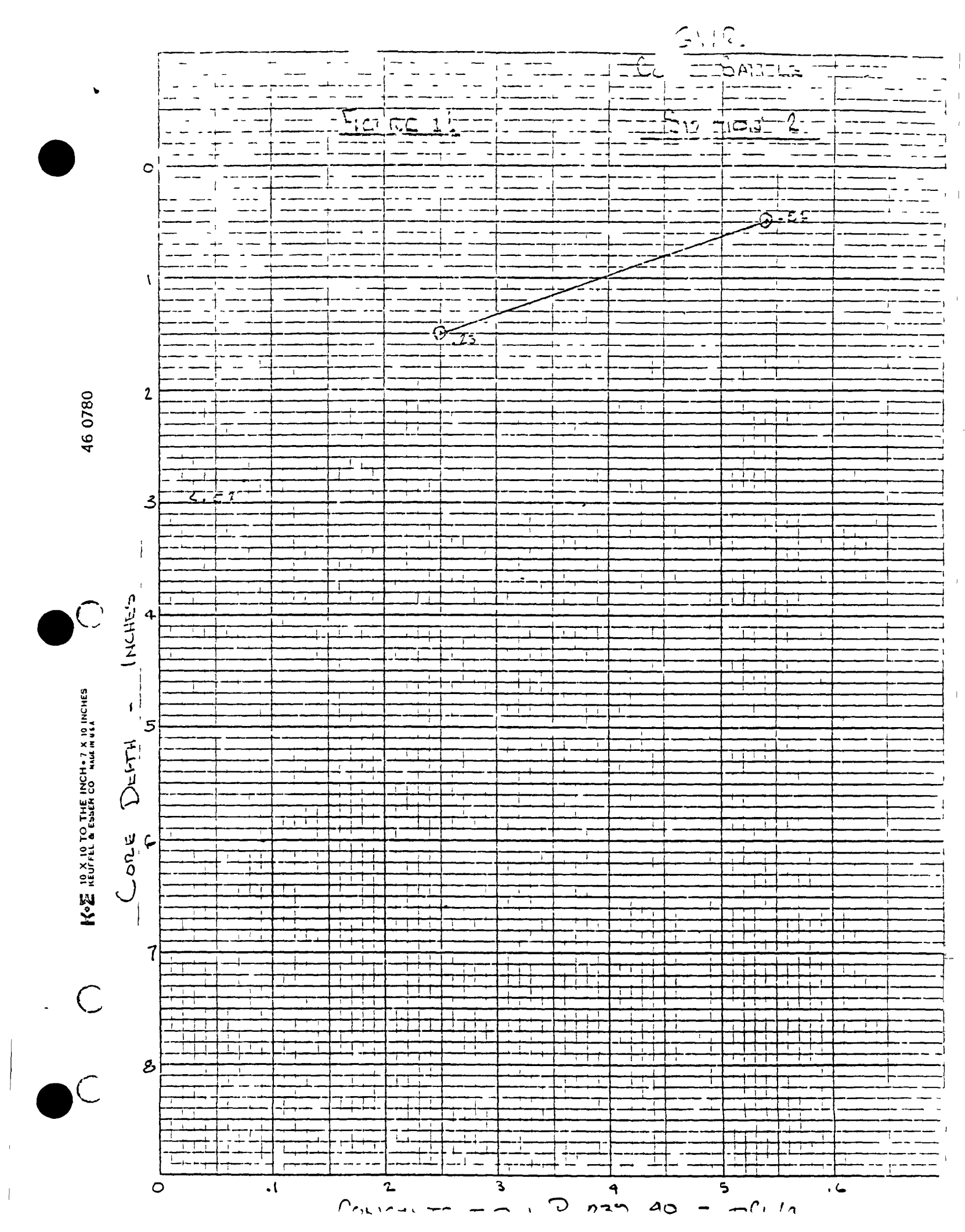
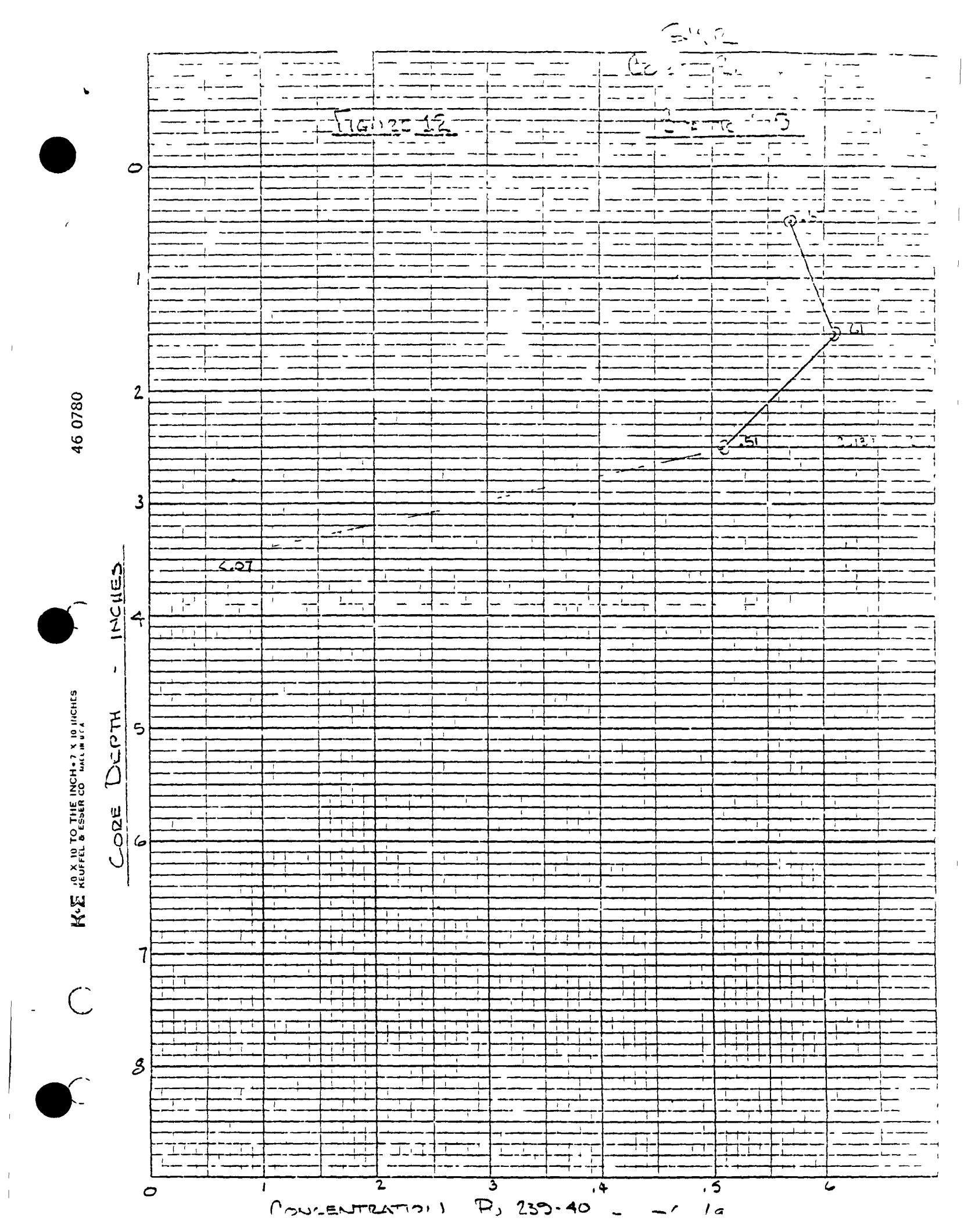
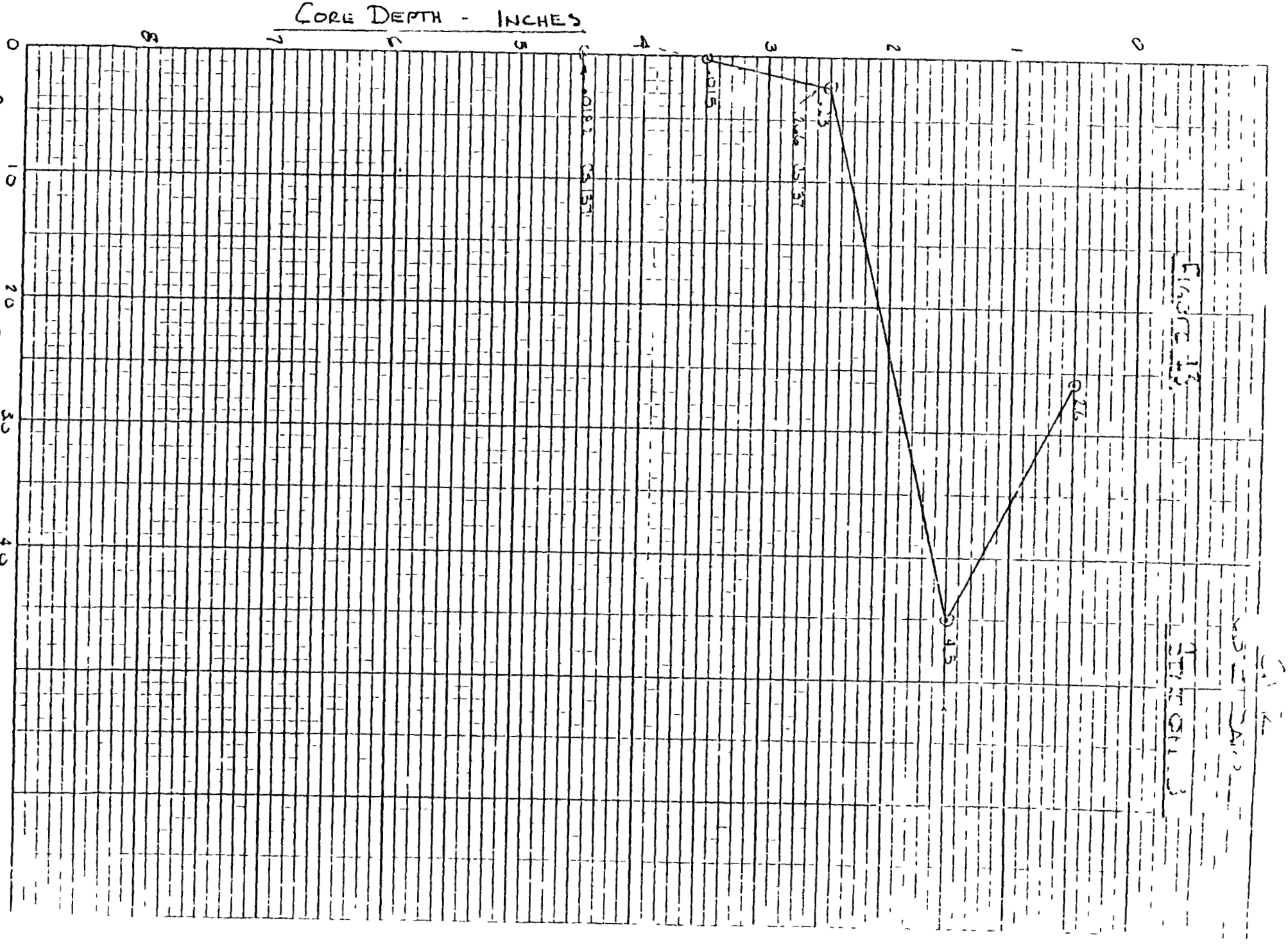


FIGURE 10
0
1
2
3
4
5
6
7
8
0105
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
CORE DEPTH - INCHES
46 0780
10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.


Core 1
Section 2
.55
.23
Core Depth - Inches
0
1
2
3
4
5
6
7
8
0
.1
2
3
4
5
.6
46 0780
K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.


CORE DEPTH - INCHES
0
1
2
3
4
5
6
7
8
0
1
2
3
.4
.5
6
CONCENTRATION Pu 239-40
.61
.51
.27
46 0780
K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.



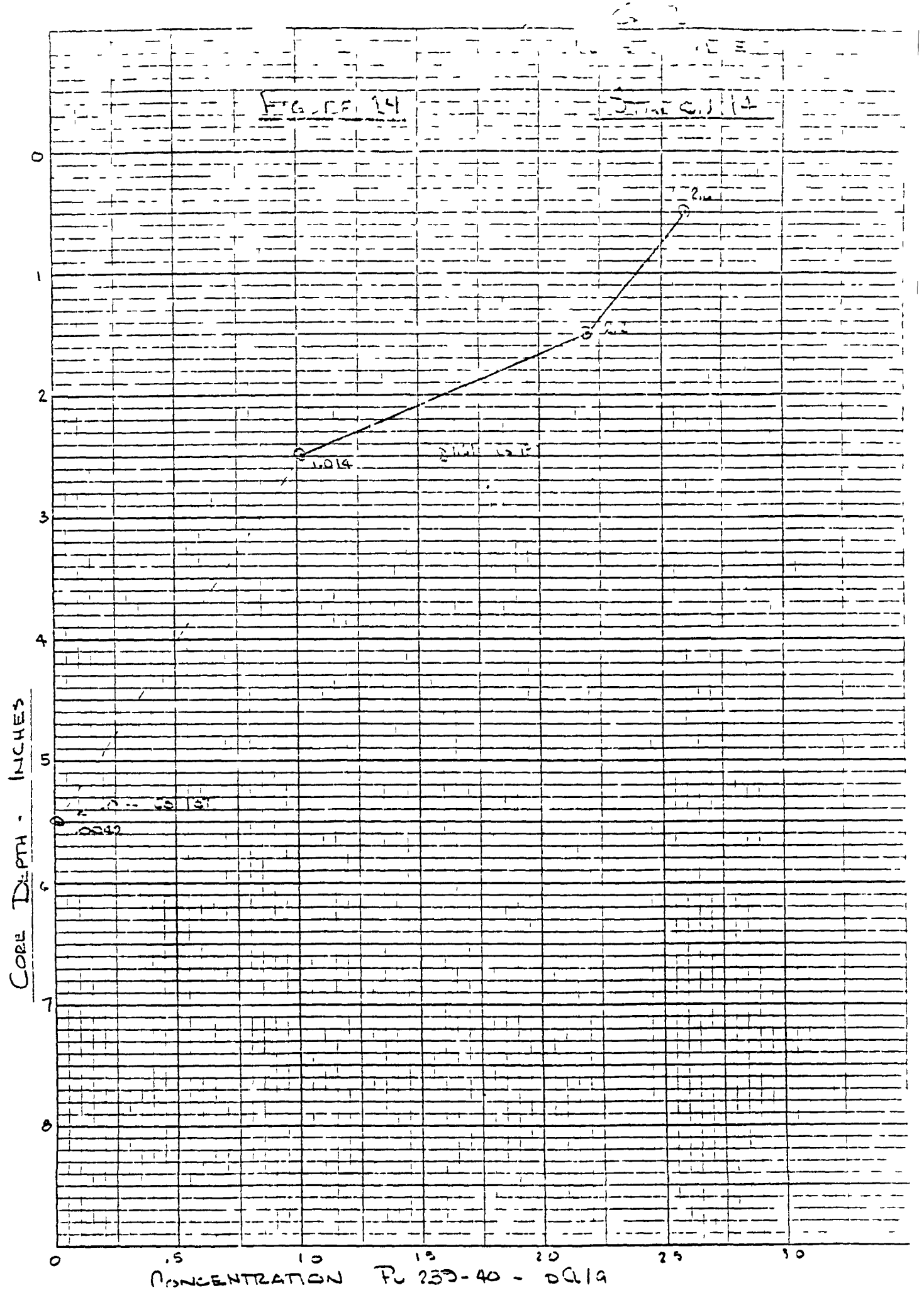


FIG. OF 14
0
1
2
3
4
5
6
7
8
0
.5
1.0
1.5
2.0
2.5
3.0
CORE DEPTH - INCHES
CONCENTRATION Pu 239-40 - dc/g
10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.
46 0780

CORE DEPTH - INCHES

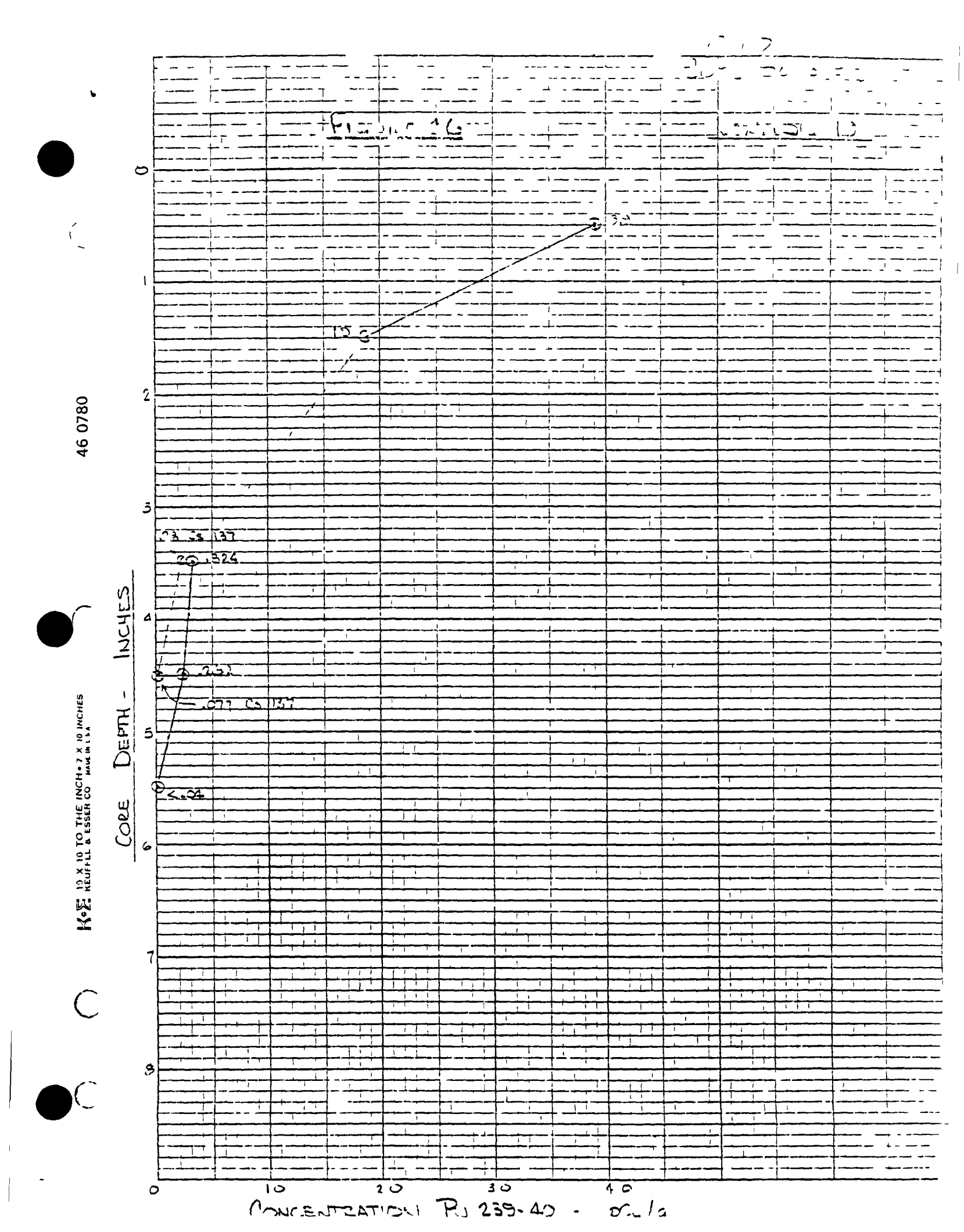


FIGURE 16
CORE DEPTH - INCHES
0
1
2
3
4
5
6
7
8
0
10
20
30
40
CONCENTRATION Pu 239-40 - dpm/g
.324
.232
.077 Cs 137
<.04
46 0780
10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.

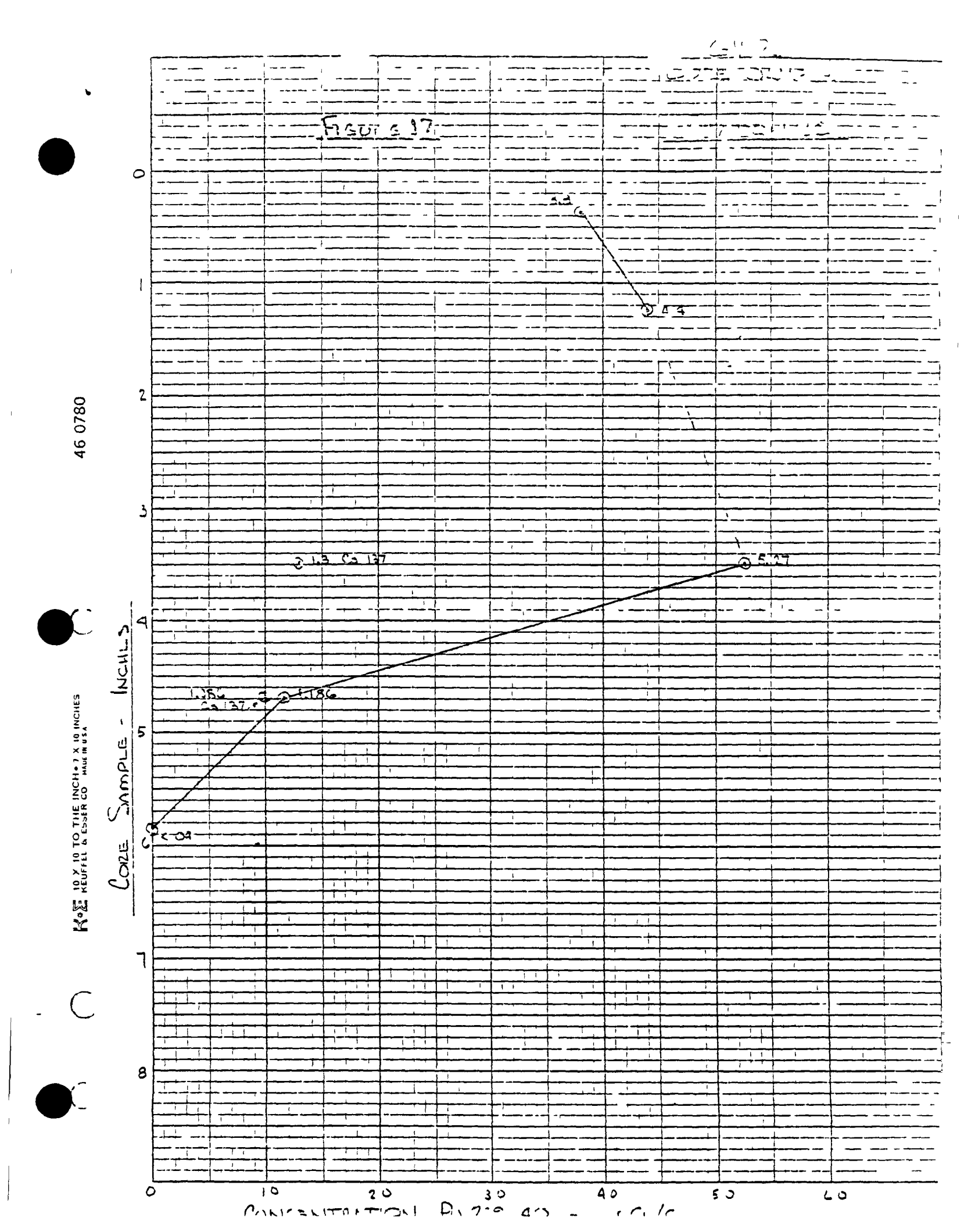


FIGURE 17
CORE SAMPLE - INCHES
0
1
2
3
4
5
7
8
0
10
20
30
40
50
60
5.13
5.37
1.86
1.85
Cs 137
Cs 137
Pu 239
46 0780
K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.

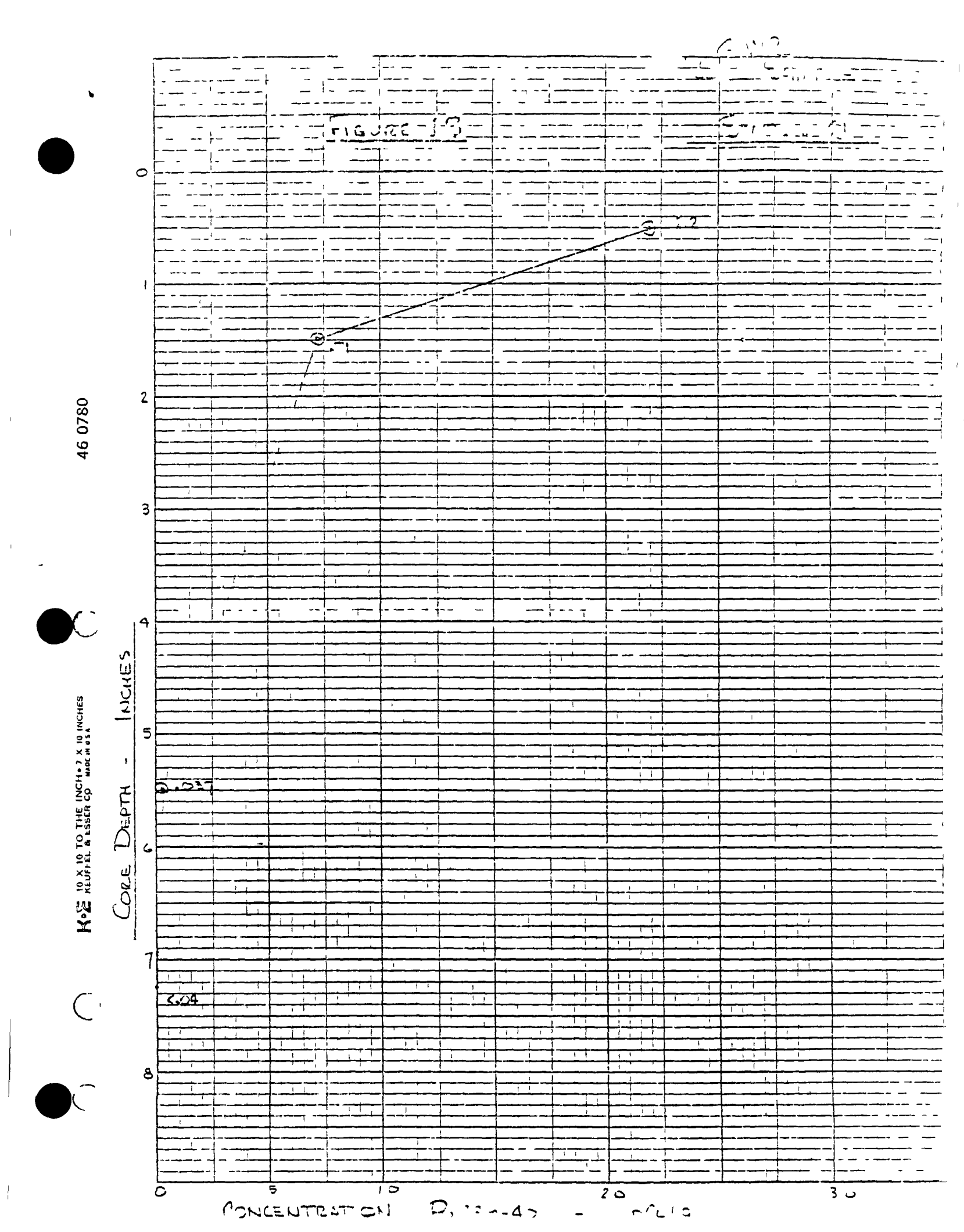


FIGURE 13
Core Depth - Inches
0
1
2
3
4
5
6
7
8
0
5
10
20
30
46 0780
K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.

TABLE I GREAT WESTERN RESERVOIR

STATION	DREDGE SAMPLE				CORE SAMPLE					
	Pu 239-40 pCi/g		Pu 238 pCi/g		DEPTH cm	Pu 239-40 pCi/g		Pu 238 pCi/g		
1	2.0	EPA	<.045	EPA	0 - 1	1.0	EPA	< 039		
	7.87	R-	.214	R-	1 - 2	1.3	EPA	<.051		
	6.45	R-	.123	R-	4.5 - 5.5	.0105	B	< 024		
					5.5 - 6.5	.10	EPA	<.06		
2	.61	EPA	<.044	EPA	0 - 1.0	.54	EPA	.041		
					1.0 - 2.0	.25	EPA	<.055		
					2.5 - 3.5	<.02	EPA	<.033		
3	2.9	EPA	.051	EPA	N.S.					
4	.46	EPA	<.058	EPA	0 - 1.4	.25	EPA	< 054		
						< 02	EPA	<.015		
5	.18	EPA	.033	EPA	0 - 1	.57	EPA			
					1 - 2	.61	EPA			
					2 - 3	.51	B	.027		
					3.0	< .072	EPA	<.034		
6	N.S.				0 - 1	47	EPA	<.045		
					1 - 2	< 07	EPA	< 1		
					3 - 4	.0091	B	<.021		
					4 - 5	< .07	EPA	<.0		
7	2.5	EPA	.11	EPA	0 - 1	3.8	EPA	<.1		
					1 - 2	.06	EPA	-		
					2 - 3	013	B	<.0		
					3 - 4	0026	B	< 0		
					4 - 5	0016	B			
					5 - 6	< 03	EPA			

TABLE I (cont

...2 TATION	Decane Sam... Pu 239-40 pCi/g		Pu 238 pCi/g		Core ...ample Depth IN	Pu 239-40 pCi/g		Pu 238 pCi/g
8	1 4	EPA	< .053	EPA	0 - 1	2.6	EPA	- 055
					1 - 2	4 5	EPA	< .04 5
					2 - 3	.23	L	004
					4 - 5	015	L	0003 3
					7 - 8	< .03	EPA	< .052
9	10	EPA	< 040	EPA	NS			
10	2.3	EPA	.11	EPA	NS			
11	1.2	EPA	< .04	EPA	NS			
12	< .06	EPA	< .051	EPA	NS			
	3.3	DE	1045	PL				
13	.44	EPA	33	EPA	0 - 1	.34	EPA	- 045
					1 - 2	016	L	007
					2 - 3	0026	L	.00023
					35 - 4 5	- 0%	EPA	< 058
14	4.1	EPA	23	EPA	0 - 1	2.6	EPA	< 045
	3 45	DE	082	PL	1 - 2	2 2	EPA	< 050
					2 - 3	1 014	L	.0 3
					5 - 6	.0042	L	.00015
					7 - 3	< 08	EPA	< .07
15	2 3	EPA	.1	EPA	0 - 1	.3 3	EPA	< 031
					1 - 2	002	L	0007 3
					2 - 3	< .07	EPA	< .0 3

TABLE I (cont'

Station	Pu 239-40 pCi/g		Am 241 pCi/g		Depth in	Pu 239-40 pCi/g		Am 241 pCi/g
16	.62	EPA	.069	EPA	0 - 1.5	1 3	EPA	< 051
					1.5 - 2 5	.55		< 052
					2 - 3	0018	L	.000 3
					3 - 4	.001	L	0004 5
					4.5 - 5.5	< .08	EPA	< .061
17	.68	EPA	< .058	EPA	N S			
18	.19	EPA	< .061	EPA	N S.			
19.	1.8	EPA	< 067	EPA	0 - 1	3.9	EPA	.054
	1.72	R=	.041	R=	1 - 2	1 9	EPA	< .05 2
					3 - 4	324	B	< .00031
					4 - 5	.232	B	< 0015
					5 - 6	< .01	EPA	< 0 1 9
20	3.8	EPA	.14	EPA	0 - .75	3.8	EPA	.072 E
					.75 - 1.75	4.1	EPA	< .063 E
					3 - 4	5.27	B	105
					4 - 5 3/8	1 186	B	.03
					5 3/8 - 6.4	< .04	EPA	< .049 E
21	.29	EPA	.089	EPA	0 - 1	2.2	EPA	< 053
	677	R=	-		1 - 2	.71	EPA	< 048
	3.57	R=	.091	R=	5 - 6	.037	B	< .00031
					6 3/4 - 7 3/4	< .04	EPA	< .046
22	N S				0 - 1	.10	EPA	< 053
					1 - 2	.025	B	< 0031
					3 - 4	< .10	EPA	< 071
					5 - 6	< 04	EPA	< 036

GREAT WESTERN RESERVOIR

TABLE I (cont

STATION	DREDGE	CORE		STATION	DREDGE	CORE	
	pCi/g	DEPTH IN.	pCi/g		pCi/g	DEPTH IN.	pCi/g
1	1.0	4.5-5.5	.013	16	1.2	2-3	.0147
						3-4	.0116
2	.97						
				17	1.2	N.S.	
3	1.1	N.S.					
				18	.94	N.S.	
4	52						
				19	1.4	3-4	28
5	.21	2-3	163			4-5	077
6	N.S.	3-4	.017	20	2.0	3-4	13
						4-5 3/3	1.08
7	1.0	2-3	.013				
		3-4	.010	21	.25	5-6	.077
		4-5	< .0057				
				22	N.S.		
8	1.0	2-3	.266				
		4-5	.0182				
9	.17	N.S.					
10	1.1	N.S.					
11	87	N.S.					
12	1.3	N.S.					
13	1.6	1-2	.0213				
		2-3	.0162				
14	2.1	2-3	1.61				
		5-6	.014				
15	2.3	1-2	.029				

BLE II. STANDLEY LAKE

Station	Dredge Sample Pu 239-40 pCi/g		Dredge Sample Pu 239 pCi/g		Core Sample Depth in	Core Sample Pu 239-40 pCi/g		Core Sample Pu 239 pCi/g
1	.11	EPA	<.071	EPA	N.S.			
2	.04	EPA	<.057	EPA	N.S			
	.85	EF						
	.65	EF						
3	.05	EPA	<.039	EPA	N.S.			
4	.04	EPA			0-1	<.06	EPA	<.045
					1-2	.012	L	.0045
					3-4	<.04	EPA	<.043
5	.03	EPA	<.11	EPA	0-1	<.09	EPA	<.051
	1.42	EF			1-2	.021	L	.00077
					4-5	<.03	EPA	<.052
6	.03	EPA	<.092	EPA	N.S			
7	.15	EPA	.053	EPA	0-1	<.06	EPA	<.043
	.83	EF	.055	EF	1-2	<.07	EPA	<.059
					4-5	.00036	L	.000049
					55-65	<.08	EPA	<.046
8	.03	EPA	<.031	EPA	0-1	<.09	EPA	<.073
					1-2	.0021	L	.00022
					35-45	<.07	EPA	<.054
9	<.02	EPA	<.041	EPA	N.S			

TABLE II (cont)

Station	Dredge Sample Pu 239-240 pCi/g		Dredge Sample Pu 238 pCi/g		Core Sample Depth in.	Core Sample Pu 239-240 pCi/g		Core Sample Pu 238 pCi/g
10	.08	EPA	<.048	EPA	N.S			
	141	RF	.041	RT				
11	03	EPA	< 048	EPA	N.S			
12	.10	EPA	<.042	EPA	0 - 1	.10	EPA	<.043
					1 - 2	< .08	EPA	<.054
					3 - 4	.0005	L	45×10^{-5}
					5 - 6	7.27×10^{-3}	L	7.27×10^{-3}
					7 - 8	< .03	EPA	< 043
13	.03	EPA	< 053	EPA	0 - 1	<.06	EPA	<.041
					1 - 2	>11	B	<.0032
					3 - 4	<.06	EPA	<.051
					8 - 9	014	B	< 0023
14	.08	EPA	<.033	EPA	N.S			
15	<.06	EPA	<.049	EPA	N.S.			
	3.16	RF	.1	RT				
16	.17	EPA	<.057	EPA	0 - 1	<.10	EPA	<.032
					2 - 3	.016	B	<.0023
					2 - 3	.109	B	< 0023
					4 - 5	.11	EPA	<.063
					6 - 7	07	EPA	<.043
					10 - 11	<.0014	B	<.00091
					11 - 12	<.04	EPA	< 050
17	<.03	EPA	< 045	EPA	0 - 1	<.	EPA	<.11
	.13	RF			1 - 2	.073	L	2
					2 - 3.5	<.04	L/A	<

1	2.3			17	.1	1-2	.1
2	1.1						
3	1.0						
4	2	1-2	.287				
5	2.0	1-2	.308				
6	2.3						
7	2.3	4-5	.0145				
8	.73	1-2	.0121				
9	.26						
10	1.0						
11	.58						
12	1.7	3-4	.0194				
		5-6	.0152				
13	.68	1-2	1.28				
14	1.9						
15	.91						
16	2.4	2-3	1.73				
		2-3 (8-9)	.0145				
		10-11	<.018				

DOCUMENT D-5

"Radionuclide Concentrations in Reservoirs, Streams and Domestic Waters Near the Rocky Flats Installation"
(1981)

by

Battelle Pacific Northwest Laboratory

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RADIONUCLIDE CONCENTRATIONS IN RESERVOIRS, STREAMS AND DOMESTIC WATERS NEAR THE ROCKY FLATS INSTALLATION

C. W Thomas
D E. Robertson

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Pacific Northwest Laboratory
Richland, Washington 99352

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Environmental Sciences
Rockwell International
Atomics International Division
Rocky Flats Plant
P O Box 464
Golden, CO 80401

ONSITE

28 R W Perkins
D E. Robertson (10)
C. W Thomas (10)
Technical Information (5)
Publishing Coordination (2)

RADIONUCLIDE CONCENTRATIONS IN RESERVOIRS, STREAMS AND DOMESTIC WATERS NEAR THE ROCKY FLATS INSTALLATION

SUMMARY

A study of the radionuclide concentrations and distributions in surface waters and sediments of Great Western Reservoir (and the streams feeding it), in Standley Lake, and in domestic tap waters from the cities of Broomfield and Westminster was conducted between April 29 and May 3, 1974 The results of this study show that $^{239-240}Pu$ and ^{241}Am concentrations in the waters and sediments of Great Western Reservoir, the streams feeding it, and in Standley Lake were above the fallout background. Plutonium-239-240 and ^{241}Am concentrations were below detection limits in Westminster tap water (<0.001 dpm/ℓ), but Broomfield tap water contained measurable but minute quantities of $^{239-240}Pu$ (0 0026 ± 0.003) and ^{241}Am (0.006 ± 0 003 dpm/ℓ). These concentrations are orders of magnitude below previously reported values published by other investigators. The $^{239-240}Pu$ concentration in Broomfield tap water is 1 5 million times below the Concentration Guide for $^{239-240}Pu$ in waters applicable to exposure of the general public (3700 dpm/ℓ), and 13,380 times lower than the EPA National Primary Drinking Water Regulation of 33 dpm/ℓ for total long-lived alpha particle activity (exclusive of radon and uranium). Such low levels of transuranic activity should pose no health hazard to area residents.

The concentrations of $^{239-240}Pu$ in surface sediments (top 5 cm) in Great Western Reservoir ranged from 0 45 to 13.4 dpm/g, and averaged 7.8 dpm/g The ^{241}Am ranged from 0 17 to 3.75 dpm/g, and averaged 1.9 dpm/g. The depth distribution of both $^{239-240}Pu$ and ^{241}Am in age-dated sediment cores (using ^{137}Cs) from Great Western Reservoir showed two periods of plutonium deposition Highest deposition corresponds to a deposition period of 1968 to 1969 The secondary maximum occurred between 1959 and 1964. Both maxima are thought to be primarily associated with recorded controlled waterborne releases from the plant but the secondary maximum will also have a component from worldwide weapons-testing fallout.

Total inventories of $^{239-240}Pu$ and ^{241}Am in the sediments of Great Western Reservoir are estimated to be 244 mCi (Pu) and 73 mCi (Am), respectively Most of this

Pu 3 3 × Am

activity is located in the deep sediment deposits at the eastern end of the reservoir

In Standley Lake, the $^{239-240}Pu$ and ^{241}Am concentrations averaged about 16 times lower than those in Great Western Reservoir Because of its greater area, however, the estimated Standley Lake sediment inventories of transuranics are a factor of only four less than those in Great Western Reservoir, i e , 61 mCi and 18 mCi, respectively, of $^{239-240}Pu$ and ^{241}Am

Pu 3 4 x Am

The ^{137}Cs concentrations in Great Western Reservoir and Standley Lake sediments are typical of the fallout background of ^{137}Cs observed in sediments from numerous waterways in the United States.

The naturally occurring ^{226}Ra in surface and domestic waters near the Rocky Flats area represents a much greater relative contribution to the public radiation exposure than do the traces of plutonium. The measured activity of ^{226}Ra is 100 to 1000 times that of $^{239-240}Pu$, and its MPC as soluble material is 167 times less than ^{239}Pu. Also, ^{226}Ra tends to be more soluble than plutonium and passes through the water treatment plants more efficiently than $^{239-240}Pu$

CONTENTS

TABLES

TABLES (continued)

TABLES (continued)

FIGURES

INTRODUCTION

The presence of plutonium in soils near the Rocky Flats plant has been well documented [1, 2, 3, 4] However, little data are available which describe the plutonium distribution in the surface waters and sediments in the Rocky Flats vicinity A study was conducted between April 29 to May 3, 1974, to determine the radionuclide input to Great Western Reservoir (GWR) and Standley Lake (SL) during the operation of the Rocky Flats plant It was proposed that this study measure the concentrations of Pu, Am and other radionuclides in waters and sediments of these reservoirs, their inlets, and associated water treatment plants to determine (1) the quantity and origin of radioactivity in the Great Western Reservoir and Standley Lake systems, (2) when the accumulation of radioactivity had occurred, and (3) to what degree the radioactivity had moved through the aqueous environs.

SAMPLING METHODS

Samples of water and sediments were collected in May of 1974 A large volume water sampler was used to collect samples from inlet streams to Great Western Reservoir (see Figure 1, Table 1). Sampling sites were located at the A-3 pond, B-4 pond, and the landfill pond which drain into Walnut Creek, South Walnut Creek and North Walnut Creek, respectively. Sampling was also conducted on Walnut Creek at the Indiana Street culvert. In addition, Great Western Reservoir and Standley Lake waters and sanitary waters from the water treatment plants for the cities of Broomfield and Westminster were sampled. The water sampler used in this study passes water through ten parallel filters (pore size equivalent to 0.5 μm) followed by passage through anion, cation and aluminum oxide sorption beds This sampling technique has several distinct advantages over conventional grab sampling methods 1) it allows for sampling extremely large volumes of water (up to 2000 liters) which greatly enhances the sensitivity for measuring ultratrace quantities of radionuclides, 2) it assures the removal of essentially all chemical forms of the radionuclides which are present in the waterways, and 3) it permits the determination of the particulate (i e , the greater than 0 5 μm fraction), anionic (or negatively charged species), cationic (or positively charged species), and nonionic

fractions (or uncharged species of the various radionuclides in the water) This characterization is very important in understanding the behavior, fate and availability of radionuclides in the aquatic environment Anionic forms of radionuclides are much more mobile in aquatic environs compared to cationic forms of the same radionuclides Anionic forms also are more difficult to remove in water treatment plants

Depending upon the turbidity of the water, up to 2000 liters of water were processed Standley Lake, Great Western Reservoir, and especially the creeks which drain into Great Western Reservoir, contained appreciable suspended loads, and plugging of the filters limited the volume of water which could be pumped through the samplers

Sediment samples were collected from Great Western Reservoir, Standley Lake, and from a sedimentation bank consisting of deposits of filter-backwash material from the Broomfield water treatment plant (see Figures 2-4, Table 2) Surface sediments were collected from a boat using a 12-inch by 12-inch Wildro-Eckman (Wildlife Supply Company, Saginaw, Michigan) dredge and using the top 2 inches of sediment for analyses. Core samples were obtained using PNL's 6-inch diameter gravity coring device which is capable of sampling sediments to depths of 24 inches Core samples were immediately frozen to prevent mixing of the sediments or migration of the radioactivity, and to thus enhance the integrity of the core. The cores were subsequently sectioned into 2-inch thick slices to determine depth profiles for the various radionuclides.

ANALYTICAL METHODS

Samples of filters, ion exchange resins, sediments, and water were packaged in a standard geometry configuration and the gamma-ray emitting radionuclides were determined by measuring in a Ge(Li)-NaI(Tl) coincidence-anticoincidence gamma-ray spectrometer This high-sensitivity gamma-ray spectrometer stores coincident and single events in separate halves of the memory The NaI(Tl) well crystal in which the Ge(Li) detector is inserted will accept environmental sample sizes up to 1.1 liter volume

The concentration of the separated plutonium radionuclides was measured by alpha energy analysis Environmental samples were spiked with ^{242}Pu tracer

and dried The samples were then leached with a HNO_3-HCl solution The residue was dried and fused with Na_2CO_3 The fused salts were dissolved in acid and combined with the acid leachate The combined solution was converted to 8M HNO_3 and the plutonium adsorbed on a Dowex 1, 50-100 mesh NO_3^- form anion exchange column The plutonium was eluted by reducing to Pu^{+3} with an HCl-HI acid mixture Nitric acid was added to the eluate and evaporated to dryness The residue was dissolved in nitric acid, the plutonium oxidized in Pu^{+4} with NO_2^- and evaporated to dryness. The residue was dissolved in hydrochloric acid and passed through a Dowex 1, 50-100 mesh, Cl^- form anion resin column Plutonium was eluted by reducing to Pu^{+3} with a HCl-HI mixture. The eluate was evaporated to dryness, dissolved in sulfuric acid and electroplated The radiochemical yield was determined by the recovery of ^{242}Pu tracer

The concentration of ^{241}Am in sediments and water samples was determined by using the described anticoincidence shielded Ge(Li) diode This instrument lowers the background and Compton interference by an order of magnitude as compared to conventional Ge(Li) diodes of the same size. Much lower detection levels could have been attained by chemical separation of the ^{241}Am followed by alpha energy analysis, but the cost of such analyses was prohibitive

ANALYTICAL RESULTS

The radionuclide measurements from water samples associated with the drainage systems of Great Western Reservoir are shown in Tables 5 through 13 and consist of samples taken from A-3 pond, B-4 pond, a landfill pond, the inlet to Great Western Reservoir (Walnut Creek), Great Western Reservoir (near dam site), and sanitary water from the Broomfield water treatment plant. The radionuclide measurements in surface sediments and core samples collected in Great Western Reservoir are shown in Tables 14 through 32 and consist of samples taken at Great Western Reservoir and at the Broomfield water treatment plant filter-backwash pond The radionuclide measurements from surface sediments and core samples from Standley Lake are shown in Tables 33 through 36 Water samples associated with Standley Lake are shown in Tables 37 and 38 and consist of samples taken at Standley Lake near the dam site and Westminster water treatment plant Summaries of radionuclide concentrations in surface

waters normalized to ^{137}Cs concentrations are shown in Table 3, and comparisons of our $^{239-240}Pu$ and ^{241}Am with previously reported data are shown in Table 4

DISCUSSION

Surface Waters

Radionuclide concentrations in surface waters which drain through the Rocky Flats area were extremely low, and frequently near detection limits This sampling was conducted during a period in which fallout from nuclear weapons testing reached its lowest point since the early 1960's. Nevertheless, ultratrace quantities of a number of fission products and transuranic radionuclides were detectable in surface waters and in Broomfield city tap water (see Tables 5-13 and Tables 37 and 39) However, there is no evidence that these fission products originated from the Rocky Flats Plant, since their relative concentrations are indistinguishable from fallout.

The drinking waters of the cities of Broomfield (derives water from Great Western Reservoir) and Westminster (derives water from Standley Lake) were analyzed to determine if Pu and Am were present No $^{239-240}Pu$ (<0 0003 dpm/ℓ) or ^{241}Am (<0.1 dpm/ℓ) could be detected in Westminster tap water. Ultra-trace amounts of $^{239-240}Pu$ were detectable in Broomfield tap water, 0.0022 dpm/ℓ being in a soluble species and 0 00029 dpm/ℓ being in a particulate form. Americium-241 concentrations were detectable only in the particulate phase, at a concentration of 0 007 dpm/ℓ. The $^{239-240}Pu$ concentrations in Broomfield tap water are 500 times lower than that reported in Radiation Data Reports[1] for the 1971 yearly average, and are 15 times lower than measurements made in 1969-70 by Poet and Martell[3] (see Table 4) Also in Radiation Data Reports,[1] a $^{239-240}Pu$ concentration of 0.89 dpm/ℓ was reported as a yearly average for Westminster tap water The value reported in RDR is about 3000 times higher than the "less than" concentrations measured in this study The sampling and analyses methods were not described in the studies reported in RDR[1] and Poet and Martell,[3] so no comparison can be made with the methods described here However, 1600 liters and 2000 liters, respectively, of Broomfield and Westminster tap waters were sampled in this study The

particulate and soluble forms of $^{239-240}Pu$ (and other radionuclides) were removed and concentrated on filters, resins and activated aluminum oxide adsorbents during the sampling process, so handling, storage and contamination problems were greatly minimized It is felt that the extreme sensitivity and care afforded by this large-volume sampling technique have provided the most accurate ultratrace measurements of $^{239-240}Pu$ ever made in these tap waters

The $^{239-240}Pu$ concentrations which were measured in Broomfield tap water (0 0025 dpm/ℓ total $^{239-240}Pu$) and Westminster tap water (<0.0003 dpm/ℓ total $^{239-240}Pu$) were 1.5 x 10^6 and 1.2 x 10^7 times, respectively, below the maximum permissible concentration in waters applicable to exposure of the general public, which is 3667 dpm/ℓ [3] These concentrations are also 13,300 and 110,000 times lower, respectively, then the EPA National Interim Primary Drinking Water Regulations for total long-lived alpha activity (exclusive of radon and uranium) which is 33 dpm/ℓ [10] Whereas the RDR[1] report showed that Standley Lake water and Westminster tap water contained about the same $^{239-240}Pu$ concentrations, the data here show that at least a 10-fold reduction of the $^{239-240}Pu$ levels occurs during the water treatment process This is accomplished primarily by removal of the particulate forms of $^{239-240}Pu$

The sampling method used in this study partitions the radionuclides into particulate, cationic, anionic and nonionic chemical forms. Such information on the chemical forms is useful in assessing the environmental behavior and fate of radionuclides in aquatic environments. Plutonium-239-240 in Standley Lake appears to be predominantly associated with the particulate matter The majority of the $^{239-240}Pu$ in Broomfield tap water is in a soluble anionic form The ^{7}Be, ^{95}Zr-^{95}Nb, ^{141}Ce, ^{144}Ce and ^{241}Am were usually associated with the suspended particulates, whereas the ^{40}K, $^{103-106}Ru$, ^{124}Sb and ^{226}Ra ★ "Natural" were predominantly present as soluble species The soluble $^{103-106}Ru$ shows a unique behavior, being present in anionic, cationic and nonionic forms The chemistry of ruthenium is complex, and numerous chemical forms are known to simultaneously exist in natural waters. During the water treatment process at the Broomfield and Westminster water works the cationic ^{106}Ru is efficiently removed, but the anionic ^{106}Ru is only slightly reduced in concentration It is interesting to note that about 60% of the filterable Pu in Broomfield tap water was collected by the anion resin

In some of the surface waters, a small fraction (5-30%) of the ^{40}K and/or ^{137}Cs was collected by either the anion resin or Al_2O_3, and in the Broomfield tap water as much as 69% of the ^{137}Cs was collected on the Al_2O_3 The most plausible explanation for this anomaly could be the presence of negatively charged colloids which contain adsorbed radioactivity, and which may have a high affinity for the anion resin or activated aluminum oxide

Sediments

Great Western Reservoir

Great Western Reservoir sampling locations are shown in Figure 2 The perimeter of the reservoir, except for the deep eastern end, appears to be rather well scoured of fine-grain sediments. The near-shoreline stations B-5, D-1, D-2, D-5 and E-4 were characterized by gravel or partial rock bottoms and no sediment cores could be obtained at these locations The bottom of the western half of the reservoir, and also near the center, contained a layer of flocculent sediments several inches thick which overlay a hard, compact clay layer, believed to be the original bottom of the reservoir The compact clay bottoms of these cores had undetectable amounts of ^{137}Cs, which suggests penetration of the coring device into the original clay bottom where no fallout ^{137}Cs had reached (see Tables 26 and 28) In the deep eastern end of the reservoir, at Stations A-2, A-3 and B-3, up to 16-22 inches of fine-textured, soft sediments overlay the compact clay bottom layer At these locations cores of 20 to 24 inches in length were collected, the bottom several inches containing the original hard clay bottom of the reservoir The low ^{137}Cs concentrations in the compact clay bottom of these cores indicate that penetration through the sediments deposited since the dam was constructed in 1955 was achieved Based on these observations and using ^{137}Cs to age date the deep cores, sedimentation rates for various locations in the reservoir could be estimated and are shown in Figure 9 Sedimentation rates in the eastern end of the reservoir appear to range from about 0 82 to 1 45 inches per year, and in the center of the reservoir range from about 0 1 to 0 46 inches per year Sedimentation rates around the perimeter of the reservoir appear to be less than 0 1 inches per year

The distribution of ^{40}K, ^{137}Cs, ^{226}Ra and ^{241}Am in surface sediments of the reservoir are shown in Figures 5 to 8 The concentrations of ^{137}Cs, ^{226}Ra and ^{241}Am are two- to threefold higher in the sediments located in the center of the reservoir compared to the sediments accumulating around the perimeter of the reservoir This may be due to erosion of the edges of the reservoir, resulting in a dilution of the contaminated sediments by the input of relatively uncontaminated clay soil. The ^{137}Cs concentrations in the reservoir sediments are typical of the fallout background levels observed at other locations in the United States (5, 6, 7, 8)

It should be pointed out that the radionuclide concentrations in the surface grab samples do not exactly correspond with the concentrations measured in the top 2 inches of the gravity cores, especially at stations along Transect A We believe that this is due to small differences in distance (tens of feet) between the actual locations where the grabs and core samples were taken The reservoir bank at the eastern end is steep So that deep gravity cores along the side of this bank could be obtained, it was necessary to back off toward the center of the reservoir several tens of feet It was subsequently found from the sediment data that radionuclide concentrations decrease in the nearshore sediments compared to those in the middle of the reservoir, and it is believed that this is the reason for the observed differences between surface grabs and the tops of the gravity cores.

A comparison of the $^{239-240}Pu$ and ^{241}Am data in this report with earlier studies reported in Radiation Data Reports(1) and by Poet and Martell(3) is shown in Table 4. The average $^{239-240}Pu$ concentrations in surface sediments measured here were 3 2 and 25 times higher, respectively, than that reported in RDR(1) and by Poet and Martell,(3) while the average ^{241}Am concentrations are 30 times higher than that reported by Poet and Martell (3) Since the distribution of radioactivity in the reservoir shows low levels near the shoreline, the samples analyzed in the RDR report and by Poet and Martell may have been obtained near the shore Such samples do not give a representative picture of the areal and depth distribution of radionuclides in the reservoir

In Figure 10 the depth distribution of the ^{137}Cs in several cores is plotted It has been demonstrated by other investigators (5, 6, 7, 8) that

^{137}Cs can be used to age date certain types of sediment cores, and that the subsurface maxima are due to abnormally high levels of fallout ^{137}Cs which had been deposited in 1963 Cesium-137 becomes strongly attached to sediment particles and becomes a tracer of sediment deposition Post-depositional diffusion or chemical exchange of the attached ^{137}Cs has been shown to be practically negligible Thus, ^{137}Cs can be used to age data sediment cores if the sedimentation rate is fairly constant and of the appropriate magnitude to be compatible with the 30-year half-life of ^{137}Cs These conditions appear to be optimum for Great Western Reservoir, and the ^{137}Cs depth profile in Figure 10 can be age dated with the ^{137}Cs maxima corresponding to sediments laid down in 1963

The distribution of $^{239-240}Pu$ in the A-2 core is shown in Figure 11, with the age vs depth scale on the right margin Two subsurface maxima in the $^{239-240}Pu$ depth distribution may be identified The larger $^{239-240}Pu$ maxima occurs at a depth of 6 inches, and corresponds to sediments deposited between 1968 and 1969 The smaller maxima occurs at a depth of 16 inches, and corresponds to sediments deposited around 1959.

A similar dating procedure may be done for the ^{241}Am distribution observed in the A-2, A-3, and B-3 cores (cf Tables 20, 21, 22, 23, 25, and 26) because of the relative constancy of the plutonium to americium ratio (Pu/Am = 3 3 ± 79 in the A-2 core). This analysis likewise indicates a primary maximum in the 1968 to 1969 period but shows the secondary peaks to range from 1959 to 1964

These transuranic sediment distributions in Great Western Reservoir are thought to be primarily associated with controlled, recorded waterborne releases from the plant but the secondary (early 1960's) maximum will also have a component from worldwide weapons testing (9)

The amount of $^{239-240}Pu$ incorporated in Great Western Reservoir sediments in excess of that derived from fallout can be estimated by dividing the ratio of $^{239-240}Pu/^{137}Cs$ in the sediments by the $^{239-240}Pu/^{137}Cs$ ratio in fallout The $^{239-240}Pu/^{137}Cs$ ratio in fallout has been reasonably constant at about 0 01 since the early 1960's ? The $^{239-240}Pu/^{137}Cs$ ratios in Sacramento, California soils (top cm) and in Columbia River sediment cores upstream from

? what about "Safety Shot" fallout ?

the Hanford project were 0 013 and 0.012, respectively, and are thus not much different than the fallout ratio The average $^{239-240}Pu/^{137}Cs$ ratio in surface sediments of Great Western Reservoir was 2 75 Thus, the apparent plutonium contribution to the surface sediments from Rocky Flats averaged about 275 times that contributed from worldwide fallout. The apparent Rocky Flats plutonium contribution relative to that derived from fallout in the subsurface sediments in the A-2 core ranged from about 260 at the surface to 80 at a depth of 12 inches

The inventory of $^{239-240}Pu$ in Great Western Reservoir sediments can be estimated as follows the reservoir can be divided into three zones of plutonium activity and sediment thickness (see Figures 12 and 13). Zone A is the deepest layer of sediments (40 to 50 cm) containing the highest plutonium activity, and is located at the eastern end of the reservoir. Zone B is a region approximately 3 times larger in area than Zone A and of intermediate sediment thickness (estimated to average about 20 cm deep) and plutonium activity, and extends to the west from Zone A. The average $^{239-240}Pu$ activity in Zone B was estimated to be about 5 dpm/g, and was obtained by using a slightly lower plutonium concentration than the average surface value, which was 6 dpm/g This reasoning was used since the average $^{239-240}Pu$ concentration in Core A-2 (0-50 cm) was 75% lower than the surface plutonium concentration in the core Only surface plutonium concentrations were measured in Zone B Zone C is the remaining area of the reservoir which is characterized by a thin deposit of sediments (estimated to average about 5 cm deep) of relatively low activity The average plutonium activity in this area is the most difficult to estimate, since only one $^{239-240}Pu$ measurement was made. Since the ^{137}Cs and ^{241}Am concentrations in the sediments from the shallow areas represented by Zone C are 1/3 to 1/2 of the concentrations in the center and east end of the reservoir, a plutonium concentration of about 1/3 to 1/2 of the maximum surface concentrations in the east end was estimated and 3 dpm/g was used A tabulation using these considerations may then be made.

	Surface Area (m^2)	Est Avg Sediment Depth (m)	Sediment Vol (cm^3)	Sediment Wt. (g)*	$^{239-240}$Pu Avg Activity (dpm/g)
Zone A	45,000	0 5	2 3 x 10^{10}	3 2 x 10^{10}	9
Zone B	120,000	0 2	2 4 x 10^{10}	3 4 x 10^{10}	5
Zone C	400,000	0 05	2 0 x 10^{10}	2 8 x 10^{10}	3

*Assuming a bulk density of 1 4 g/cm^3 for the sediments This is a typical value for fine grained lake and river sediments

Upon multiplying the sediment masses (g) by the average $^{239-240}$Pu concentrations in each zone, these three sediment zones contain the following estimated inventories of $^{239-240}$Pu

	dpm	mCi
Zone A	29 x 10^{10}	131
Zone B	17 x 10^{10}	77
Zone C	8 x 10^{10}	36
Total	54 x 10^{10}	244

Thus, a total of approximately 244 mCi (or 3 9 g) of $^{239-240}$Pu is present in the reservoir sediments. Over 50% of this inventory is located in the deep sediment deposits at the east end of the reservoir which represent only about 8% of the total surface area of the reservoir

The average ^{241}Am/$^{239-240}$Pu ratio in surface and subsurface sediments is about 0.30 Thus, an ^{241}Am inventory of about $\frac{(244\ mCi)(0.30)}{}$ = 73 mCi is also present in the reservoir

Two 18-inch sediment cores were collected from a sedimentation bank consisting of deposits of filter-backwash material (alum floc) from the Broomfield water treatment plant (see Table 2 and Figure 4) The radionuclide analyses of these cores (see Tables 2, 31, 32, and Figure 4) showed ^{137}Cs and ^{241}Am concentrations which were typical of the surface sediments in Great Western Reservoir The $^{239-240}$Pu concentration in these cores, based on extrapolations from the ^{241}Am/$^{239-240}$Pu ratio in the reservoir sediments, was estimated to average 4 5 dpm/g This sedimentary material appeared to consist primarily of processed alum floc Since the radionuclide concentrations in this material were similar to those observed in surface sediments of the

reservoir, it would indicate that scavenging by the alum floc of soluble forms or very small suspended particles (containing relatively high concentrations of adsorbed radionuclides) was occurring during the water treatment process

Standley Lake

Although Standley Lake is about four times larger than Great Western Reservoir, the sedimentation characteristics of the two water bodies appear to be quite similar The area of high sedimentation in Standley Lake is located in the deep water at the eastern end of the lake adjacent to the dam At this location (SL-5G) a 17-inch long gravity core was obtained which showed a ^{137}Cs depth distribution quite similar to those observed at stations A-2, A-3 and B-3 at Great Western Reservoir. A sedimentation rate of about 1 0 inches/year was estimated for this area of relatively fast sediment deposition The western 2/3 of the lake has a sediment bottom characterized by a 1- to 6-inch layer of flocculent sediments which overlay a layer of hard, compact clay which appears to be the original lake bottom

The average $^{239-240}Pu$ concentation in Standley Lake surface sediments was 0.49 dpm/g, which is about 16 times lower than in Great Western Reservoir (see Table 3) The ^{241}Am concentrations were near the detection limit of the direct counting method used, but an average concentration of 0.28 ± 14 dpm/g was measured in four samples. Based on the relative sizes and radionuclide contents of Standley Lake and Great Western Reservoir, it is estimated that the $^{239-240}Pu$ and ^{241}Am inventories in Standley Lake are about 1/4 of those in Great Western Reservoir, or about 61 mCi of $^{239-240}Pu$ and 18 mCi of ^{241}Am

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Table 1

LARGE VOLUME WATER SAMPLES

Location	Date	Volume Sampled (liters)	No of Samples
Westminster City Water Supply	4-29-74	2006	1
Standley Lake	4-29-74	710	1
Broomfield City Water Supply	4-30-74	1665; 1514	2
Great Western Reservoir	4-30-74	297; 212	2
Walnut Creek & Inlet to GWR	4-30-74	70.8, 58 3	2
B-4 Pond	4-30-74	153	1
A-3 Pond	5-01-74	97.4	1
North Walnut Creek Below Rocky Flats Landfill	5-01-74	136	1

Table 2

SEDIMENT CORES

Great Western Reservoir and Standley Lake

Station	Core Length (inches)
A-1	8
A-2	24
A-3	20
A-4	6
B-3	20
C-2	6
C-3	6
C-4	10
E-4	6
*HC-1	18
*HC-2	18
**SL-5	20

*Broomfield Water Treatment Plant Effluent Basin

**Standley Lake

Table 3

COMPARISON OF $^{239-240}Pu$ AND ^{241}Am CONCENTRATIONS IN SURFACE WATERS AND LAKE SEDIMENTS

Water	$^{239-240}Pu$ (dpm/ℓ)			^{241}Am (dpm/ℓ)		
	Battelle*	Radiation Data Reports**	Poet & Martell***	Battelle*	Radiation Data Reports**	Poet *** & Martell
A-3 Pond	--	1.5	1 8	0.51 (partic <4 2 (sol.)	--	0 42
B-4 Pond	--	4 2	--	0 42 (partic) <2.22 (sol)	2 49	--
Walnut Creek	--	5.0	--	1.5 (partic) <8.2 (sol)	1 33	--
Great Western Reservoir	--	0 44	--	0.13 (partic.) <0.67 (sol.)	0 64	--
Broomfield tapwater	0 00029 (partic) 0 00220 (sol) †	1 2	0.037	0.007 (partic) <0.16 (sol)	--	--
Standley Lake	0 00170 (partic) < 0 00110 (sol.) †	0 87	--	<0 04 (partic.) <0 60 (sol)	0 16	--
Westminster tapwater	< 0 0002 (partic) < 0 0001 (sol) †	0.89	--	<0.004 (partic) <0 12 (sol)	--	--
Sediments	$^{239-240}Pu$ (dpm/gm)			^{241}Am (dpm/gm)		
Great Western Reservoir	7 75 (avg of 8 surface sed)	2 40 (avg of 2)	0 3 (avg. of 2)	1.91 (avg of 10 surface sed)	--	0 064 (avg of 2)
Standley Lake	0 49 (avg of 3 surface sed)	0 64 (avg of 2)	--	0 28 (avg of 4 surface sed)	--	--

† The $^{239-240}Pu$ concentrations in Broomfield and Westminster tap waters is compared to a maximum permissible concentration of ^{239}Pu in water applicable to exposure of the general public of 3667 dpm/ℓ

* April, 1973

** 1971 yearly avg

*** 8/69 to 2/70

Table 4

RADIONUCLIDE CONCENTRATIONS IN SOUTH WALNUT CREEK WATER AT RETENTION POND B-4

dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	12 8± 42	3 53±.68	<1.88	263± 135
^{40}K	<1.56	<5.32	<3.81	<1 28
^{54}Mn	.204±.023	.160±.054	<.192	< 036
^{60}Co	.006±.003	012±.007	<.007	< 003
^{90}Sr	*	*	*	*
^{95}Zr	7.54±.139	2.35±.245	.736± 238	412± 056
^{95}Nb	14.1±.12	4.29± 232	2.27±.182	.484± 045
^{103}Ru	.768±.040	.512± 092	.529±.129	198± 026
^{106}Ru	8.41±.111	4 87±.169	13.4±.252	2 24± 080
^{125}Sb	1.18±.103	<.329	<.614	6 66± 734
^{137}Cs	.759±.039	.402±.093	<.244	< 037
^{141}Ce	.333±.053	<.155	<.267	< 035
^{144}Ce	13.7±.270	2.85±.392	<1.18	< 174
^{226}Ra	1.14±.472	13.2±1.37	<3.89	2 55± 352
^{228}Ac	464±.114	1.71± 427	<1 22	.362± 115
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	419±.234	< 405	< 690	< 106

* Not measured

Table 5

RADIONUCLIDE CONCENTRATIONS IN WALNUT CREEK WATER AT RETENTION POND A-3

dpm/liter

Isotope	Filter	Cation	Anion
^{7}Be	6 38±1.07	<1.98	<1 90
^{40}K	2.24± 88	15.9±2.33	14 2±2.33
^{54}Mn	< 019	< 234	< 232
^{60}Co	007±.004	.014± 011	< 012
^{90}Sr	*	*	*
^{95}Zr	.202±.031	< 393	< 396
^{95}Nb	.413± 028	<.231	<.230
^{103}Ru	.051±.010	<.237	<.231
^{106}Ru	295±.066	< 136	.705± 172
^{125}Sb	<.047	< 643	< 640
^{137}Cs	.205±.023	< 238	< 239
^{141}Ce	<.022	< 308	< 300
^{144}Ce	.674±.060	<1.25	<1 21
^{226}Ra	1.08± 181	4 68±2 27	<1
^{228}Ac	.284± 084	<1.23	<1.37
^{238}Pu	*	*	*
^{239}Pu	*	<.0033	*
^{241}Am	.511±.068	<1 58	<1 55

*Not measured

Table 6

RADIONUCLIDE CONCENTRATIONS IN NORTH WALNUT CREEK WATER AT LANDFILL POND

dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	.870±.098	<2.72	<2.97	<0 5
^{40}K	< 913	<6.86	<6.52	<1 0
^{54}Mn	.032±.009	<.323	<.290	<0 05
^{60}Co	< 003	<.008	<0 007	< 002
^{90}Sr	*	*	*	*
^{95}Zr	.322±.026	<.591	.662±.289	<0 2
^{95}Nb	590±.020	<.352	.921±.205	.884± 015
^{103}Ru	.036±.010	<.304	<.345	<0 1
^{106}Ru	.917±.051	1.11±.128	2.52±.161	.928± 051
^{125}Sb	.070±.026	<.842	<.874	<0 3
^{137}Cs	.223±.014	<.354	<.364	045± 008
^{141}Ce	<.027	<.405	<.424	<0 2
^{144}Ce	.794±.056	<1.68	<1.79	<0 5
^{226}Ra	<.161	<6.07	<5.93	< 027
^{228}Ac	.160±.060	<1.77	<1.28	.010± 007
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	< 220	<2.80	<2.83	*

*Not measured

Table 7
RADIONUCLIDE CONCENTRATIONS IN WALNUT CREEK
AT THE POINT OF ENTRANCE TO THE GREAT WESTERN RESERVOIR

dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	3 50±.644	<4.06	<5.30	<2
^{40}K	11 1±4.5	<25.8	<22.6	<7
^{54}Mn	<.104	<.508	<1.06	<0 3
^{60}Co	<.006	039±.019	< 018	036± 010
^{90}Sr	*	*	*	*
^{95}Zr	1.01± 172	<.887	<2.02	<0 5
^{95}Nb	2.24±.154	<.617	<1.05	<0 3
^{103}Ru	.204±.055	<.434	<1.17	<0 3
^{106}Ru	.450±.115	.472±.224	.699±.248	< 112
^{125}Sb	<.298	<1.11	<3.09	<0 5
^{137}Cs	.804±.098	<.563	<1.22	< 024
^{141}Ce	.159±.065	<.587	<1.45	<0 3
^{144}Ce	3.76±.374	<2.26	<6.06	<1
^{226}Ra	11.9±1.12	30.6±5.16	21.1	<10
^{228}Ac	3.96±.486	<3.53	<6.34	049± 025
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	2.17±.261	<1.84	<9.75	*

*Not measured

Table 8

RADIONUCLIDE CONCENTRATIONS IN WALNUT CREEK WATER AT INDIANA STREET

dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	2.10±.27	<1.89	<1 81	<0 5
^{40}K	4.4 ±1.75	8.26±2.80	<5.49	<2
^{54}Mn	<.054	<.183	<.195	<0 05
^{60}Co	<.005	<0 02	<0 02	< 01
^{90}Sr	*	*	*	*
^{95}Zr	.608±.064	<.381	< 427	<0 1
^{95}Nb	1.22±.072	< 189	<.196	<.22
^{103}Ru	.138±.024	<.193	<.182	<0 5
^{106}Ru	.743±.017	.349±.210	1.22±.210	<0 3
^{125}Sb	.165± 051	864±.257	.480±.259	<0 3
^{137}Cs	.492±.049	.324±.113	.396±.114	<0 1
^{141}Ce	.090±.027	<.317	<.322	<0 1
^{144}Ce	2.21±.166	1.05±.11	<1.17	<0 3
^{226}Ra	4.82±.45	6.89±3 65	8 70±1.90	<2
^{228}Ac	1.20±.20	1.67±.56	<1.27	<0 3
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	848±.111	<2.49	<2.54	*

*Not measured

Table 9

RADIONUCLIDE CONCENTRATIONS IN GREAT WESTERN RESERVOIR WATER NEAR DAM

Water Sample #1

dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	1.94±.110	< 687	<.262	< 079
^{40}K	<.694	9.11±1 15	<1.39	959±.243
^{54}Mn	.022±.007	< 062	<.030	< 010
^{60}Co	<0 005	<0 02	<0 02	<0 007
^{90}Sr	*	*	*	*
^{95}Zr	.540±.031	< 026	< 093	< 025
^{95}Nb	1.24±.041	280± 005	.139±.030	056± 009
^{103}Ru	082±.009	< 082	.065± 019	< 009
^{106}Ru	945 ± 025	.358±.130	.626±.142	088± 015
^{125}Sb	.066±.018	<.183	<.085	048± 013
^{137}Cs	.19 ±.003	.130±.055	<.042	010± 003
^{141}Ce	<0 1	< 065	<.034	< 010
^{144}Ce	<0.1	<.260	<.176	046± 021
^{226}Ra	.531±.087	2.55±.603	1.52±.261	637± 089
^{228}Ac	.114±.040	< 363	<.262	<.056
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	121± 029	< 360	<.171	< 051

*Not measured

Table 10

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR WATER NEAR DAM

Water Sample #2

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	2.07±.107	<.352	<.635	< 263
^{40}K	<.761	10.5±1.34	<1.95	<2 59
^{54}Mn	.023±.006	<.047	<.064	< 026
^{60}Co	<.002	.006±.005	< 005	< 002
^{90}Sr	*	*	*	*
^{95}Zr	.520±.033	< 122	<.125	< 056
^{95}Nb	1.18±.031	.297±.045	<.074	078± 015
^{103}Ru	.079±.008	<.042	<.064	<.025
^{106}Ru	.919±.038	.535±.068	.680±.077	339± 081
^{125}Sb	.063±.017	<.113	<.182	104±.037
^{137}Cs	.159±.013	.064± 014	<.080	082± 011
^{141}Ce	.040±.006	< 049	< 114	< 046
^{144}Ce	1.95± 055	<.204	< 376	< 162
^{226}Ra	.533± 086	4.09± 451	< 132	< 54
^{228}Ac	.131± 040	.472± 064	<.42	019± 012
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	.127± 032	<.280	<.509	< 398

*Not measured

Table 11

RADIONUCLIDE CONCENTRATION IN WATER FROM BROOMFIELD WATER TREATMENT PLANT MORNING SHIFT

dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	<.0088	<.061	< 068	< 02
^{40}K	<.092	.268±.016	<.410	< 1
^{54}Mn	<.001	<.010	<.0087	< 003
^{60}Co	< 0002	<.0006	<.0006	< 0002
^{90}Sr	*	*	*	*
^{95}Zr	.0043±.0016	< 015	< 015	< 015
^{95}Nb	.0117±.0012	<.010	<.015	< 015
^{103}Ru	<.0011	<.009	.042±.007	
^{106}Ru	.018±.003	.057±.011	.352±.013	018± 003
^{125}Sb	<.0024	<.020	< 026	
^{137}Cs	.0025±.0007	.032±.002	<.0091	<.003
^{141}Ce	<.0010	<.011	<.012	< 004
^{144}Ce	.022±.003	<.043	<.043	< 01
^{226}Ra	.042±.004	.873±.002	1.32±.123	< 03
^{228}Ac	.0074±.0018	.171±.044	<.075	< 0006
^{238}Pu	*	00021*	.00014*	< 00018
^{239}Pu	*	.00095 *	0017±.0002	< 00018
^{241}Am	<.0060	<.033	<.035	*

* Error bar limits are between 20-50%

* Not measured

Table 12

RADIONUCLIDE CONCENTRATION IN WATER FROM BROOMFIELD WATER TREATMENT PLANT AFTERNOON SHIFT

dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	<.015	<.131	<.201	< 05
^{40}K	1.53±.078	.706±.133	<.441	<0 2
^{54}Mn	<.0014	<.013	<.024	< 005
^{60}Co	< 0002	<.0007	< 0007	< 0002
^{90}Sr	*	*	*	*
^{95}Zr	.0077±.0022	<.022	<.042	< 01
^{95}Nb	.019±.0021	.0158±.0059	< 271	195± 070
^{103}Ru	.0028±.0009	< 013	< 241	< 01
^{106}Ru	.024±.004	.061±.012	.311±.129	019± 003
^{125}Sb	<.0043	<.035	<.066	< 02
^{137}Cs	.0023±.0011	.034±.0076	<.028	082± 011
^{141}Ce	.0023±.0012	<.019	<.031	< 01
^{144}Ce	.029±.0057	<.082	<.128	< 05
^{226}Ra	.160±.019	.682±.129	.533±.231	<0 2
^{228}Ac	.0143±.007	.248±.049	<.142	<0 1
^{238}Pu	<.00029	00020±.00016	.00019± 00016	< 00016
^{239}Pu	.00028 ±.00014	.00099±.00015	.0013±.00020	<.00016
^{241}Am	006±.003	<.112	<.203	*

*Not measured

Table 13

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Surface** Sediments - Transect A

dpm/gram

Isotope	A-1	A-2	A-3	A-4	A-5
^{7}Be	.258±.101	.345±.072	< 19	.272± 072	< 15
^{40}K	28 8±1.04	36.4±.494	26.7±1.06	37 4±.516	22 9± 927
^{54}Mn	<.026	<.016	<.016	.025± 008	< 019
^{60}Co	< 01	< 01	< 01	<.01	< 01
^{90}Sr	*	*	*	*	*
^{95}Zr	074±.028	.089±.018	.081±.030	.085±.018	< 042
^{95}Nb	102± 018	.113±.011	.161± 023	118± 111	069± 016
^{103}Ru	<.02	<.014	<.023	.021± 007	< 018
^{106}Ru	.237±.098	.320±.073	.281±.198	.191±.074	< 340
^{125}Sb	<.061	.077±.022	.048±.033	.123± 021	< 047
^{137}Cs	.636±.039	1.14± 014	1.20±.053	.905± 018	620± 036
^{141}Ce	<.029	<.027	< 019	.027± 013	< 033
^{144}Ce	.268±.086	.224± 051	.393±.085	.209±.050	094± 074
^{226}Ra	4.68±.327	3.80±.166	3.63±.309	3.07± 164	3 79± 276
^{228}Ac	1.57±.166	1.85± 072	1.65±.167	1.93± 073	1 11± 137
^{238}Pu	*	*	*	*	*
^{239}Pu	*	*	*	*	*
^{241}Am	286±.110	1.28±.125	1 62± 134	1 24±.122	532± 098

**Depth of surface sample is 5 cm

*Not measured

Table 14

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR NEAR ROCKY FLATS

Surface** Sediments - Transect B
dpm/gram

Isotope	B-1	B-2	B-3	B-4
^{7}Be	.450±.144	.288±.150	.374±.075	723± 140
^{40}K	29.9±1.20	31.8±1.02	30.4± 695	33 0± 602
^{54}Mn	<.033	<.030	<.017	036± 015
^{60}Co	< 0 01	<0 01	<0 01	<0 01
^{90}Sr	*	*	*	*
^{95}Zr	097± 028	165±.036	.100±.018	163± 028
^{95}Nb	.156±.025	.150±.023	.204± 015	.209± 020
^{103}Ru	<.019	<.030	<.014	017± 014
^{106}Ru	.332±.261	<.319	.325± 138	.404± 136
^{125}Sb	.221±.040	.114±.043	.151±.022	108± 041
^{137}Cs	1.79±.072	1.24±.042	1.67±.038	1.92± 037
^{141}Ce	028±.020	.079±.027	.044± 011	021± 021
^{144}Ce	.353±.097	.234±.102	.498±.056	494± 095
^{226}Ra	5.10±.381	3.59±.335	4.92±.204	5 78± 299
^{228}Ac	1.64±.205	1.42±.146	1.75±.107	2 55± 134
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	1.90± 153	1.74±.246	1.64± 084	1 51± 143

** Depth of surface sample is 5 cm.

* Not measured.

Table 15

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Surface**Sediments - Transect C

dpm/gram

Isotope	C-1	C-2	C-3	C-4	C-5
^{7}Be	.363±.145	.665± 123	1.01±.130	.990± 136	< 17
^{40}K	34.5± 618	41.6±1.00	42.9±1.02	43.8±1.03	41 3±1 01
^{54}Mn	043±.016	<.028	.038±.013	< 027	< 026
^{60}Co	<0.01	<0.01	<0.01	<0.01	<0 01
^{90}Sr	*	*	*	*	*
^{95}Zr	099±.028	.195±.025	.330±.032	.279±.030	< 03
^{95}Nb	296±.019	.270± 023	.579±.030	441±.028	080± 014
^{103}Ru	.016±.015	<.022	.056±.013	030± 012	< 018
^{106}Ru	615±.142	.836± 228	.675±.235	.611±.229	< 41
^{125}Sb	133±.044	.294± 038	.313±.040	.287± 037	< 05
^{137}Cs	2.59±.043	2.96±.063	3.19±.066	2.94±.064	491±.028
^{141}Ce	042±.022	.048± 023	.040±.022	< 046	127± 021
^{144}Ce	508±.101	.993± 106	1.39± 110	1.21± 111	195± 084
^{226}Ra	6 31±.317	9.37± 390	8 57±.393	9.91±.398	9 85± 378
^{228}Ac	2 83± 144	2 91± 180	2.76± 181	2.29± 192	2 12± 154
^{238}Pu	*	*	*	*	*
^{239}Pu	*	*	*	*	*
^{241}Am	2.01± 152	2.12± 092	2.45±.095	1.89± 092	328± 066

** Depth of surface sample is 5 cm.

* Not measured.

Table 16

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR
Surface**Sediments - Transect D
dpm/gram

Isotope	D-1	D-2	D-3	D-4
^{7}Be	<.377	< 381	<.444	626± 121
^{40}K	37.4±1.74	35 9±1.72	33.4±.969	40.6± 989
^{54}Mn	<.046	<.044	<.048	< 024
^{60}Co	<0.01	<0.01	<0.01	<0 01
^{90}Sr	*	*	*	*
^{95}Zr	<.068	<.079	.118±.043	172± 026
^{95}Nb	.119±.031	<.061	.190±.030	279± 022
^{103}Ru	< 032	<.037	< 047	< 022
^{106}Ru	<.718	<.821	<.476	911± 222
^{125}Sb	<.102	<.102	.244± 070	205± 036
^{137}Cs	1.30±.078	2.24±.102	1.51±.057	2 74±.061
^{141}Ce	.078±.039	<.078	<.066	090± 021
^{144}Ce	.353±.169	<.345	<.291	877± 100
^{226}Ra	7.68±.655	7.28±.652	5 46±.533	8 72± 389
^{228}Ac	2.99±.314	3.67±.345	2 36±.208	2 89± 174
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	510± 130	.491± 128	1.81± 265	2 14± 090

* Not measured.
**Depth of surface sample is 5 cm.

Table 17

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Surface** Sediments - Transect E

dpm/gram

Isotope	E-1	E-2	E-3	E-4
^{7}Be	< 377	<.350	< 516	< 398
^{40}K	34.9±.846	39.4±1.75	34.6±1 06	33 4± 827
^{54}Mn	.079±.023	<.042	<.053	< 044
^{60}Co	< 0.01	<0 01	< 0.01	<0 01
^{90}Sr	*	*	*	*
^{95}Zr	132± 041	<.076	<.096	160± 039
^{95}Nb	.115±.024	.183±.034	<.070	181± 029
^{103}Ru	<.041	<.037	<.056	< 044
^{106}Ru	<.414	<.414	<.528	518± 212
^{125}Sb	< 123	<.112	<.158	<.205
^{137}Cs	1.35±.047	1.77± 090	2.19±.070	2 39± 059
^{141}Ce	<.060	<.068	.099±.037	< 061
^{144}Ce	<.258	.490±.169	.329± 165	< 271
^{226}Ra	5.59± 460	5.97±.619	5.41±.590	5 16±.465
^{228}Ac	3.58±.203	2.23± 280	2 87± 225	2 53± 190
^{238}Pu	*	*	*	*
^{239}Pu	*	*	*	*
^{241}Am	< 079	2.00±.156	1.35±.285	811± 224

* Not measured

** Depth of surface sample is 5 cm.

Table 18

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Surface* Sediments - Transect F

dpm/gram

Isotope	F-1	F-2
^{7}Be	< 389	< 367
^{40}K	33 7±.833	32 1± 818
^{54}Mn	< 042	<.043
^{60}Co	<0.01	<0.01
^{90}Sr	**	**
^{95}Zr	.096±.039	.174± 038
^{95}Nb	<.053	<.051
^{103}Ru	<.042	< 042
^{106}Ru	<.416	< 388
^{125}Sb	<.121	<.115
^{137}Cs	2.10±.056	1.09± 043
^{141}Ce	<.059	<.059
^{144}Ce	<.254	< 247
^{226}Ra	5 56±.450	5.34± 452
^{228}Ac	2.59±.180	2 93± 196
^{238}Pu	**	**
^{239}Pu	**	**
^{241}Am	1.39± 224	666± 211

* Depth of surface sample is 5 cm thick.

** Not measured

Table 19

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect A-1

dpm/gram

Isotope	A-1-1	A-1-2	A-1-3
^{7}Be	<.131	<.184	< 317
^{40}K	40.4±.99	39.0±.98	34 9±1 69
^{54}Mn	<.028	<.025	< 044
^{60}Co	<0 01	<0 01	<0 01
^{90}Sr	1.21±.312	**	1 49± 361
^{95}Zr	<.042	<.035	<.061
^{95}Nb	.048±.013	.034±.012	<.043
^{103}Ru	<.015	<.020	<.016
^{106}Ru	<.302	<.413	<.352
^{125}Sb	.283±.037	.107±.021	< 085
^{137}Cs	3.44±.069	3.19±.066	.234± 036
^{141}Ce	<.044	<.044	< 072
^{144}Ce	.624±.096	< 173	<.294
^{226}Ra	8.84±.379	12.0±.380	7 97± 75
^{228}Ac	2.99±.215	2.52±.17	2.45± 30
^{238}Pu	.129±.013	**	< 011
^{239}Pu	6.21±.079	**	.11 ± 005
^{241}Am	2.16±.091	1.04±.079	< 086

* Core sections are 5 cm thick

** Not measured

Table 20

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect A-2

dpm/gram

Isotope	A-2-1	A-2-2	A-2-3	A-2-4	A-2-5	A-2-6
^{7}Be	<.247	<.841	<.448	<.263	<.406	< 314
^{40}K	34.5±1.53	44.3±2.40	35.5±1.41	30.9±1.70	37.0±1.27	35 7±1 07
^{54}Mn	.026±.016	<.090	<.051	<.041	< 046	< 035
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01	<0 01
^{90}Sr	1.05±.303	1.75±.391	1.05±.300	2.04±.416	1.21±.312	1.77± 377
^{95}Zr	<.072	<.182	<.100	<.061	<.089	< 073
^{95}Nb	.099±.023	<.099	<.044	<.033	<.044	< 039
^{103}Ru	<.028	<.083	<.042	<.030	<.040	< 032
^{106}Ru	.610±.305	<.789	.58 ±.240	<.711	<.365	< 312
^{125}Sb	.23 ±.045	.19 ±.126	.28 ±.072	.23 ±.064	.132± 060	190± 100
^{137}Cs	2.14±.088	2.81±.12	2.05± 072	3 55±.132	2.58±.067	2.46±.056
^{141}Ce	<.045	<.149	<.077	< 028	<.087	< 053
^{144}Ce	.52 ±.111	.49 ±.278	.33 ±.146	<.239	<.253	< 208
^{226}Ra	5.06_.420	5 22±.898	5.85±.491	6.52±.526	4.26± 444	3.97± 360
^{228}Ac	2.18±.244	2.40±.406	2.07±.221	1.97±.258	1.60±.199	1.74± 158
^{238}Pu	281±.019	.352±.021	.249± 017	.336±.022	.290± 019	082± 011
^{239}Pu	12 0±.041	11.4± 055	7.51±.072	18.23+.091	9 97±.058	2.36± 021
^{241}Am	3.75±.214	4.28±.698	2.42± 361	4 13± 254	2.11± 326	710± 245

* Core sections are 5 cm thick

Table 21

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect A-2 (cont.)

dpm/gram

Isotope	A-2-7	A-2-8	A-2-9	A-2-10	A-2-11
^{7}Be	<.276	<.221	< 108	<.362	<.153
^{40}K	31.6±1.36	34.8± 673	31.0±.692	38.8±1.26	30 6±1 09
^{54}Mn	<.036	<.023	<.017	<.042	<.026
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01
^{90}Sr	2.69±.538	2.15±.430	1.72±.385	1.16±.310	0 95± 286
^{95}Zr	<.130	<.163	<.025	<.085	< 049
^{95}Nb	<.026	<.077	<.012	<.040	< 022
^{103}Ru	<.030	<.022	<.013	< 043	< 019
^{106}Ru	<.506	<.204	<.257	<.190	< 314
^{125}Sb	380±.058	.220±.036	<.047	.130±.059	<.043
^{137}Cs	5.28± 130	4.12±.046	3 10±.051	2.57±.065	690± 018
^{141}Ce	<.048	.072±.038	<.051	<.070	< 039
^{144}Ce	<.209	< 139	< 102	<.249	< 170
^{226}Ra	4.76±.416	4.85±.244	5.16±.215	4.10±.431	4.26± 317
^{228}Ac	1.86±.219	1.82±.105	1.88±.111	2 08±.194	1 57± 163
^{238}Pu	124± 014	.154± 015	.235± 018	.142±.015	008± 010
^{239}Pu	4.28± 028	5.71± 043	11.3± 054	7 68± 029	032± 007
^{241}Am	1.87±.166	2.42± 182	3.31± 101	2.16± 318	195± 099

* Core sections are 5 cm thick

Table 22

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect A-3

dpm/gram

Isotope	A-3-1	A-3-2	A-3-3	A-3-4	A-3-5
^{7}Be	<.334	<.189	< 391	< 199	< 453
^{40}K	47 0±1.36	40.6±.998	46.9±2.04	41.7±1.00	49 6±2.06
^{54}Mn	<.034	<.026	<.047	<.026	< 050
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01
^{90}Sr	1.29±.322	**	**	**	**
^{95}Zr	.138±.037	< 039	<.072	<.038	<.069
^{95}Nb	.272±.033	<.025	<.045	< 024	< 039
^{103}Ru	<.034	<.021	<.047	<.022	< 045
^{106}Ru	.874±.338	<.448	1.39±.535	.868± 237	< 887
^{125}Sb	.349±.054	.287±.038	.516±.092	.469± 046	< 337
^{137}Cs	3.49±.097	3.67± 071	5.15±.163	4.36±.077	5.62± 167
^{141}Ce	<.059	<.043	<.096	<.062	<.186
^{144}Ce	1.19±.137	.863±.101	1.65±.220	.824±.106	< 372
^{226}Ra	10 3±.553	8.47± 381	10.5±.809	10.3±.404	10 6±.820
^{228}Ac	2.99±.243	2.91±.179	3.67±.420	2.82±.172	3 29± 362
^{238}Pu	.195±.015	**	**	**	**
^{239}Pu	13.4±.041	**	**	**	**
^{241}Am	3.22±.140	3.15±.103	2.55±.190	2 20±.093	5 02± 223

* Core sections are 5 cm thick

** Not measured

Table 23

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect A-3 (cont.)

dpm/gram

Isotope	A-3-6	A-3-7	A-3-8	A-3-9	A-3-10
^{7}Be	< 197	<.384	<.232	<.391	<.225
^{40}K	44.2±1.03	42.8±1.85	45.2±1.04	47.9±1.93	43.3±1 03
^{54}Mn	<.025	<.047	<.030	< 049	< 027
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01
^{90}Sr	**	**	**	**	1.80± 393
^{95}Zr	< 037	<.068	<.037	<.059	< 037
^{95}Nb	< 024	<.050	<.023	<.043	< 047
^{103}Ru	<.023	< 041	<.025	< 191	< 023
^{106}Ru	< 434	<.805	<.450	<.842	<.424
^{125}Sb	.245±.039	.358±.071	.560±.050	.724±.093	.231± 037
^{137}Cs	5.61± 088	6.40±.172	9.65±.114	9 68±.210	5 94± 091
^{141}Ce	<.066	< 083	< 076	< 080	< 046
^{144}Ce	<.227	< 337	<.199	<.351	< 188
^{226}Ra	9 64±.405	9.10±.747	9.67±.421	11.4±.784	10 9±4 14
^{228}Ac	2.90±.184	3.37±.335	2.83±.176	2.67±.342	2 74±.176
^{238}Pu	**	**	**	**	< 011
^{239}Pu	**	**	**	**	11 ± 005
^{241}Am	1.92±.092	1.24±.157	1.58±.089	2.17± 170	4 70± 116

* Core sections are 5 cm thick

** Not measured

Table 24

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect A-4

dpm/gram

Isotope	A-4-1	A-4-2	A-4-3
^{7}Be	<.391	< 174	< 103
^{40}K	48.6±1.98	41.2±1.01	41 7±1 83
^{54}Mn	<.044	<.026	<.047
^{60}Co	<0 01	<0 01	<0 01
^{90}Sr	<.425	**	**
^{95}Zr	<.057	<.034	< 075
^{95}Nb	<.051	<.024	< 041
^{103}Ru	<.045	<.018	< 038
^{106}Ru	<.827	**	< 818
^{125}Sb	<.126	<.103	< 120
^{137}Cs	2.66±.111	1.58±.047	940± 068
^{141}Ce	<.084	<.069	< 085
^{144}Ce	< 361	<.182	< 340
^{226}Ra	9.62±.745	8.44± 375	9 10± 745
^{228}Ac	3.16±.344	2.93±.171	3 10± 310
^{238}Pu	.099±.011	**	**
^{239}Pu	3.97±.021	**	**
^{241}Am	1.38±.153	566±.073	558± 140

* Core sections are 5 cm thick

** Not measured

Table 25

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect B

dpm/gram

Isotope	B-3-1	B-3-2	B-3-3	B-3-4	B-3-5
^{7}Be	<.441	<.609	<.426	<.362	<.243
^{40}K	36 0±.912	36.6±1.22	39.2±.890	44.4±1.89	43 1±1.09
^{54}Mn	.077±.024	<.061	<.047	<.052	< 031
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01
^{90}Sr	1.45± 363	**	**	**	**
^{95}Zr	<.118	<.117	<.081	<.070	< 040
^{95}Nb	<.046	<.073	<.052	<.041	< 026
^{103}Ru	<.047	<.065	< 046	<.045	< 026
^{106}Ru	542±.232	<.637	<.433	<.783	< 464
^{125}Sb	.396±.073	.311±.106	.435±.073	<.144	.519± 049
^{137}Cs	2.49±.064	3.48±.098	4.41±.077	5.66±.161	8 53± 114
^{141}Ce	<.066	<.092	<.065	<.082	< 048
^{144}Ce	.692±.146	.705± 202	<.275	<.346	< 198
^{226}Ra	6.21±.516	6.51±.730	7.38±.519	10.6±.743	9 92± 431
^{228}Ac	2 95±.208	3.32±.293	3.17±.201	3.18± 316	3 02± 190
^{238}Pu	.241±.019	**	**	**	**
^{239}Pu	11.8±.044	**	**	**	**
^{241}Am	2.41±.267	2.09±.352	3 09±.265	1.23±.156	1 89± 096

* Core sections are 5 cm thick

** Not measured

Table 26

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect B(cont.)

dpm/gram

Isotope	B-3-6	B-3-7	B-3-8	B-3-9	B-3-10
^{7}Be	<.326	< 539	< 273	<.472	< 262
^{40}K	38.0±.631	36.0±1.12	39.9±.640	38.4±1.15	36.7± 618
^{54}Mn	<.033	<.059	<.033	<.058	< 050
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01
^{90}Sr	**	**	**	**	850± 283
^{95}Zr	<.054	<.098	<.054	<.102	< 056
^{95}Nb	<.037	<.065	<.038	<.066	< 036
^{103}Ru	<.035	<.064	<.030	<.053	< 029
^{106}Ru	<.311	<.566	< 291	<.490	<.290
^{125}Sb	.367±.056	<.178	<.087	<.141	< 083
^{137}Cs	6 49±.066	4.61± 102	1.06±.031	<.067	< 047
^{141}Ce	<.048	<.085	<.085	<.077	< 042
^{144}Ce	<.197	<.353	<.186	<.326	< 178
^{226}Ra	6 28±.372	5.55±.652	6 44±.346	5.68±.601	6 22± 334
^{228}Ac	2.67±.146	3.50± 264	3.00±.142	2.65± 247	2 91± 137
^{238}Pu	**	**	**	**	< 007
^{239}Pu	**	**	**	**	083± 007
^{241}Am	3.34±.191	3.34±.339	<.170	0 107	< 313

* Core sections are 5 cm thick

** Not measured

Table 27

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect C-1,2,3

dpm/gram

Isotope	C-1-1	C-2-1	C-2-2	C-3-1	C-3-2	C-3-3
^{7}Be	2.44±.337	<.325	<.173	<.366	<.165	< 274
^{40}K	24.6±1.54	39.8±1.80	46.6±1.06	42.0±1.84	39 1±.982	37 9±1 76
^{54}Mn	< 057	<.045	<.034	<.053	<.027	< 045
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01	< 0 01
^{90}Sr	**	.830±.314	**	1.30±.347	**	**
^{95}Zr	699± 093	<.061	<.035	<.067	<.032	< 062
^{95}Nb	1.58±.091	<.039	<.023	< 055	.036±.012	< 033
^{103}Ru	.094±.031	<.035	<.019	< 030	<.019	< 035
^{106}Ru	3 55±.551	<.769	<.458	1.00±.362	< 414	<1 04
^{125}Sb	.440±.080	<.087	<.048	.257±.065	<.055	< 087
^{137}Cs	1.70± 077	.507±	<.027	3.06±.118	1 12± 040	< 042
^{141}Ce	421±.053	<.075	<.047	< 081	< 042	< 070
^{144}Ce	2.91± 255	<.325	<.199	< 353	<.175	< 294
^{226}Ra	33.6±1.18	7.54±.658	8.73±.397	8.96±.693	7.64± 365	7 14± 594
^{228}Ac	2.70± 304	3.02±.316	3.66±.188	2.72± 303	3.10± 175	2 37± 279
^{238}Pu	**	.030±.010	**	.103±.011	**	**
^{239}Pu	**	.450±.010	**	5.99±.028	**	**
^{241}Am	1 45±.201	<.172	<.099	1.43±.156	.426±.070	< 215

* Core sections are 5 cm thick

** Not measured

Table 28

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect C-4

dpm/gram

Isotope	C-4-1	C-4-2	C-4-3	C-4-4	C-4-5
^{7}Be	<.216	<.180	<.386	<.168	< 180
^{40}K	40.6±.984	40.9±1.01	46 3±1.90	43.5±.873	42 3±1 01
^{54}Mn	<.027	<.026	<.036	<.022	<.026
^{60}Co	<0 01	< 0 01	< 0 01	< 0 01	<0 01
^{90}Sr	2 13±.444	**	**	**	1 14±.316
^{95}Zr	.064±.021	<.042	<.051	<.031	< 034
^{95}Nb	.112±.016	<.026	< 055	<.020	< 023
^{103}Ru	<.022	<.022	<.043	<.017	< 019
^{106}Ru	.782±.243	<.440	<.780	<.372	< 409
^{125}Sb	.304±.038	.355±.041	.329±.073	<.095	< 049
^{137}Cs	3.53±.069	5.06±.083	7.08±.179	3.76±.060	363± 024
^{141}Ce	.083± 023	<.046	<.085	<.060	< 042
^{144}Ce	.882±.101	<.198	<.336	<.155	< 179
^{226}Ra	7.00±.383	10.5±.407	9.55±.744	9 07±.336	8 06± 370
^{228}Ac	2.97±.167	3.52±.179	3 03±.312	2 85± 149	2 93± 171
^{238}Pu	.182± 012	**	**	**	017± 010
^{239}Pu	8 16± 037	**	**	**	344±.009
^{241}Am	2.41±.094	2.58±.096	1.58±.169	2.17±.068	< 168

* Core sections are 5 cm thick

** Not measured

Table 29

RADIONUCLIDE CONCENTRATION IN GREAT WESTERN RESERVOIR

Core* Sediments - Transect E-2

dpm/gram

Isotope	E-2-1	E-2-2	E-2-3
^{7}Be	<.257	<.239	< 450
^{40}K	37.2±.617	36.2±.607	34.2±1.08
^{54}Mn	<.030	<.033	< 056
^{60}Co	<0 01	<0 01	<0 01
^{90}Sr	**	**	**
^{95}Zr	< 052	< 051	< 091
^{95}Nb	<.037	<.032	< 064
^{103}Ru	<.028	<.024	< 051
^{106}Ru	<.271	<.266	< 491
^{125}Sb	<.083	<.076	< 136
^{137}Cs	580±.025	<.034	< 060
^{141}Ce	<.041	<.040	< 073
^{144}Ce	<.176	< 168	< 305
^{226}Ra	5.14±.321	5.34±.315	4.66± 573
^{228}Ac	2 69± 133	2.48±.126	2 75± 234
^{238}Pu	**	**	**
^{239}Pu	**	**	**
^{241}Am	.786±.157	.483±.147	< 280

* Core sections are 5 cm thick

** Not measured

Table 30

RADIONUCLIDE CONCENTRATION IN SEDIMENTS FROM THE BROOMFIELD WATER TREATMENT PLANT

dpm/gram

Isotope	HC-1-1	HC-1-2	HC-1-3	HC-1-4	HC-1-5	HC-1-6
^{7}Be	2.38±.339	<.263	<.893	<.377	< 481	< 285
^{40}K	26.0±1.57	30.8±.567	19 1±1.35	25.9±.677	26.5± 831	21 7± 509
^{54}Mn	< 053	<.031	<.103	<.043	<.055	< 032
^{60}Co	<0 01	<0 01	<0 01	<0 01	<0 01	<0 01
^{90}Sr	**	**	**	**	**	**
^{95}Zr	587±.081	<.053	<.174	<.072	< 094	< 053
^{95}Nb	1.39±.087	<.036	<.109	.088±.027	.136±.033	060± 020
^{103}Ru	< 065	<.030	<.100	<.041	< 053	< 031
^{106}Ru	2.30±.499	<.059	2.20±.528	1.81±.231	1.05±.279	574± 153
^{125}Sb	.300±.079	.186± 045	<.307	.494±.066	.449±.087	236± 049
^{137}Cs	1.85±.094	2.03±.039	2.05±.112	2.31±.053	2 59± 067	1 98± 040
^{141}Ce	.543±.055	.155±.022	.449±.075	.427±.034	437± 042	.374± 026
^{144}Ce	3.18±.256	.283± 092	<.590	866±.138	752± 176	< 205
^{226}Ra	35.3±1.20	13.7±.381	28.7±1.37	37.4± 662	37.2± 809	29 8± 488
^{228}Ac	2.31±.316	2.45±.128	2.10±.364	2.40±.167	10 6± 339	2 78± 130
^{238}Pu	**	**	**	**	**	**
^{239}Pu	**	**	**	**	**	**
^{241}Am	1.09± 196	1.23±.173	<1.15	1 20± 267	684± 323	954± 205

* Core sections are 5 cm thick

** Not measured

Table 31

RADIONUCLIDE CONCENTRATION IN SEDIMENTS FROM THE BROOMFIELD WATER TREATMENT PLANT

Core* Sediments dpm/gram

Isotope	HC-2-1	HC-2-2	HC-2-3	HC-2-4	HC-2-5	HC-2-6
^{7}Be	<.805	<.269	<.546	<.702	<.300	< 844
^{40}K	20.8±1.31	29.7±.561	19.2±.878	24.5±1.16	21.4±.536	23 9±1 39
^{54}Mn	<.092	<.031	<.063	<.072	<.033	< 087
^{60}Co	<0 01	<0 01	< 0 01	< 0 01	<0 01	<0 01
^{90}Sr	**	**	**	**	**	**
^{95}Zr	<.163	<.052	<.107	.331±.071	<.058	< 154
^{95}Nb	<.116	<.035	.133±.037	691±.061	.124±.022	< 129
^{103}Ru	<.091	<.029	<.063	<.075	< 033	< 091
^{106}Ru	2.59±.536	911±.150	2.05±.346	1.80±.380	663± 168	< 868
^{125}Sb	<.274	.212±.045	.268±.091	.339±.106	.120±.055	< 314
^{137}Cs	2 02±.104	2.05± 039	1.78± 066	1.81±.083	2.12± 044	2 39± 116
^{141}Ce	519±.071	.172±.023	.434± 046	.215± 052	.441±.028	355± 072
^{144}Ce	.880±.033	<.191	<.378	1.53±.228	.295± 110	< 566
^{226}Ra	38.2±1.40	14.2±.383	29.5±.853	20.7±.952	34 5± 540	33 1±1 35
^{228}Ac	2.27±.379	2.73± 129	2.35±.238	2.21±.018	2.13± 138	2 96± 388
^{238}Pu	**	**	**	**	**	**
^{239}Pu	**	**	**	**	**	**
^{241}Am	1.21±.545	1.39±.175	<.695	2 19± 411	2.09± 228	2 30± 581

* Core sections are 5 cm thick

** Not measured

Table 32

RADIONUCLIDE CONCENTRATION IN STANDLEY LAKE

Surface* Sediments - Grab Samples

dpm/gram

Isotope	1	2	3	4
^{7}Be	.255±.090	<.190	<.175	831± 132
^{40}K	36.9±.625	43.6±1.03	30.1±.87	46 7± 231
^{54}Mn	<.034	<.028	< 022	< 030
^{60}Co	<0 01	< 0 01	<0 01	<0 01
^{90}Sr	**	**	**	**
^{95}Zr	<.059	< 039	.060±.019	220± 029
^{95}Nb	.199±.020	077±.016	.064±.014	445± 028
^{103}Ru	<.031	<.021	<.016	028±.013
^{106}Ru	.801±.156	<.450	<.376	879±.250
^{125}Sb	.306±.049	<.070	<.048	355±.038
^{137}Cs	2.72±.017	2.08±.054	.931±.037	2 95± 064
^{141}Ce	<.047	<.045	<.050	.108± 025
^{144}Ce	.898±.102	<.136	.328±.083	1 52± 116
^{226}Ra	7.30±.389	7.84±.378	5.87±.338	12 2± 428
^{228}Ac	2.91±.139	3.50±.193	2.48±.160	3 64± 179
^{238}Pu	.023±.009	**	.020±.010	**
^{239}Pu	.512±.028	**	.636± 031	**
^{241}Am	291±.169	182±.071	<.054	149± 075

* Depth of surface sediment is 5 cm

** Not measured

Table 33

RADIONUCLIDE CONCENTRATION IN STANDLEY LAKE

Surface* Sediments - Grab Samples (cont)
dpm/gram

Isotope	5	6	7	8
^{7}Be	< 254	<.272	<.262	< 524
^{40}K	26.3±.530	35 8±.608	29.2±.550	48 6±1 3
^{54}Mn	<.178	<.032	<.031	< 063
^{60}Co	<0.01	<0 01	<0 01	<0 01
^{90}Sr	**	**	**	**
^{95}Zr	.098±.025	<.057	<.054	< 111
^{95}Nb	<.033	<.038	<.034	< 073
^{103}Ru	<.027	<.029	.047±.014	< 058
^{106}Ru	.580±.138	.384±.144	<.283	< 575
^{125}Sb	.120±.042	.165±.045	.127±.042	<.162
^{137}Cs	1.79±.037	1.25±.033	1.43±.034	112± 039
^{141}Ce	<.037	< 043	<.042	<.087
^{144}Ce	278±.086	<.187	<.179	<.371
^{226}Ra	5.19±.454	6.18±.13	5.02± 324	10 1± 722
^{228}Ac	2.31±.127	2.74±.142	2.95±.134	3.56± 162
^{238}Pu	**	**	< 007	**
^{239}Pu	**	**	.329±.021	**
^{241}Am	<.162	<.317	<.150	485± 325

* Depth of surface sediment is 5 cm

** Not measured

Table 34

RADIONUCLIDE CONCENTRATION IN STANDLEY LAKE

Core* Sediments

dpm/gram

Isotope	5-1	5-2	5-3	5-4
^{7}Be	<.412	<.265	<.260	< 542
^{40}K	35.2±1.68	47.6±1.29	45.9±1.31	50 2±2.46
^{54}Mn	<.042	<.032	<.036	<.071
^{60}Co	0 01	0 01	0 01	0.01
^{90}Sr	**	**	**	**
^{95}Zr	<.078	<.053	<.051	< 101
^{95}Nb	.102± 031	< 034	<.032	< 068
^{103}Ru	<.034	<.028	<.029	< 053
^{106}Ru	<.786	<.624	1.21±.310	< 485
^{125}Sb	.358±.072	.569±.059	.411±.053	< 205
^{137}Cs	2.44±.106	4.31±.092	4.72±.099	6.10± 203
^{141}Ce	<.073	<.056	<.057	< 105
^{144}Ce	.795±.170	1.05±.134	.573±.124	< 448
^{226}Ra	8 76±.633	12.2±.532	11.7±.538	12 6±1.02
^{228}Ac	2.34±.300	3.83±.251	3.87±.243	3 67±.466
^{238}Pu	**	**	**	**
^{239}Pu	**	**	**	**
^{241}Am	<.112	<.186	<.190	374±.182

* Core sections are 5 cm thick

** Not measured

Table 35

RADIONUCLIDE CONCENTRATION IN STANDLEY LAKE

Core* Sediments (cont)

dpm/gram

Isotope	5-5	5-6	5-7	5-8
^{7}Be	<.262	< 278	<.212	<.292
^{40}K	47.6±1.19	52.2±1.22	56.3±1.14	39 2±.638
^{54}Mn	<.031	<.031	<.028	<.035
^{60}Co	0 01	0 01	0 01	0 01
^{90}Sr	**	**	**	**
^{95}Zr	<.042	< 049	<.041	< 062
^{95}Nb	< 030	<.031	<.029	< 040
^{103}Ru	< 026	<.028	<.023	< 032
^{106}Ru	<.530	<.522	<.471	<.308
^{125}Sb	.315±.046	677± 058	<.074	<.095
^{137}Cs	6.49± 102	10.8±.131	4.65±.058	1 66±.037
^{141}Ce	<.055	<.057	<.051	< 047
^{144}Ce	<.222	<.235	<.210	<.203
^{226}Ra	14.4±.508	17.2+.570	17.2± 496	6 81± 369
^{228}Ac	3.82±.224	4.01± 230	4.02±.194	4 58±.160
^{238}Pu	**	**	**	**
^{239}Pu	**	**	**	**
^{241}Am	186±.086	.351±.089	< 080	.391± 174

* Core sections are 5 cm thick

** Not measured

Table 36

RADIONUCLIDE CONCENTRATION IN STANDLEY LAKE WATER NEAR DAM

Water Samples - dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	864±.030	<.287	<.302	<0 1
^{40}K	< 170	7.70±.436	<.686	<0 2
^{54}Mn	0116±.0019	<.030	<.034	<0 01
^{60}Co	.001±.0005	.006±.002	<.002	<0 001
^{90}Sr	**	**	**	**
^{95}Zr	224±.0085	.090± 029	.077±.033	<0 03
^{95}Nb	.385±.0068	.138±.020	.293±.024	117± 003
^{103}Ru	.275±.025	~ 031	<.035	<0 01
^{106}Ru	153±.022	.231±.025	.549±.109	.119±.011
^{125}Sb	.066± 0066	<0.1	<.095	<0 03
^{137}Cs	.030± 003	.063±.020	<.039	010± 002
^{141}Ce	020±.003	<.0412	<.044	<0 02
^{144}Ce	.947±.018	.299±.089	<.189	<0 07
^{226}Ra	.052±.034	2.11±.316	2.27±.340	<1
^{228}Ac	<.022	<.162	<.182	< 002
^{238}Pu	<.00028	<.00062	<.00044	< 00052
^{239}Pu	.0017± 0002	<.00062	<.00044	< 00052
^{241}Am	~ 049	<.282	<.302	**

* Not measured

Table 37

RADIONUCLIDE CONCENTRATION IN WATER FROM THE WESTMINSTER WATER TREATMENT PLANT

Water Samples - dpm/liter

Isotope	Filter	Cation	Anion	Al_2O_3
^{7}Be	.012±.004	<.091	<.139	<0 03
^{40}K	<.076	1 24±.119	<.627	<0 2
^{54}Mn	<.0009	<.011	<.014	<0 04
^{60}Co	< 0002	<.0005	< 0005	<0 0002
^{90}Sr	*	*	*	*
^{95}Zr	<.0024	<.018	<.025	<0 01
^{95}Nb	.0087±.0009	<.010	.040±.011	<0 01
^{103}Ru	.0027± 0006	< 010	< 021	<0 05
^{106}Ru	.025± 003	.064±.009	.363±.013	022± 003
^{125}Sb	.0022± 0010	<.029	<.044	<0 01
^{137}Cs	<.0012	<.012	<.014	<0 005
^{141}Ce	<.001	<.013	<.016	<0 005
^{144}Ce	.012±.002	<.056	<.068	<0 02
^{226}Ra	<.014	2.47±.148	.482 ±.151	<0 4
^{228}Ac	< 0056	<.061	<.111	<0 02
^{238}Pu	<.00029	< 00006	<.00007	< 00013
^{239}Pu	<.00029	<.00006	<.00007	< 00013
^{241}Am	<.0046	<.092	<.050	*

* Not measured

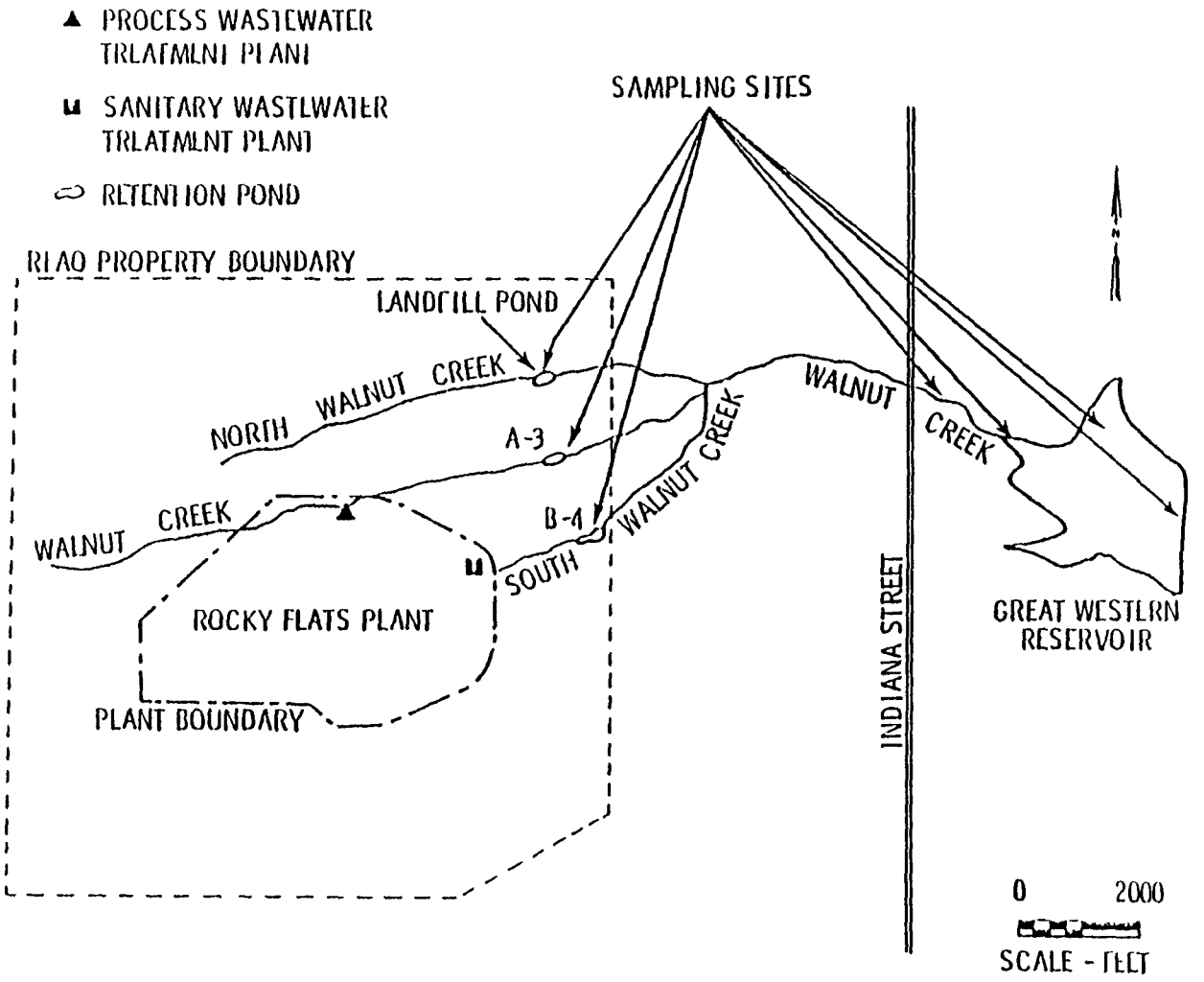

Figure 1 Water Sampling Sites at Great Western Reservoir and Associated Waterways

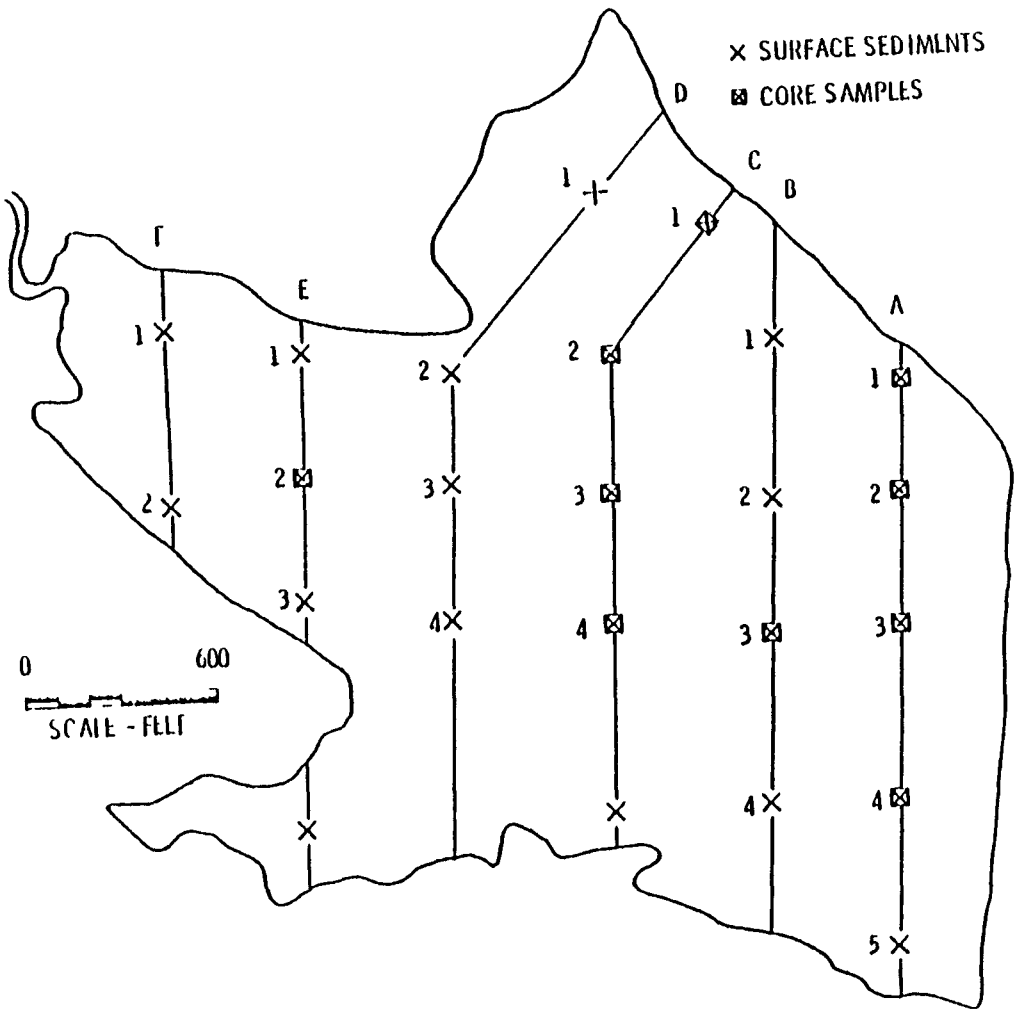

Figure 2. Sediment Sampling Stations at Great Western Reservoir

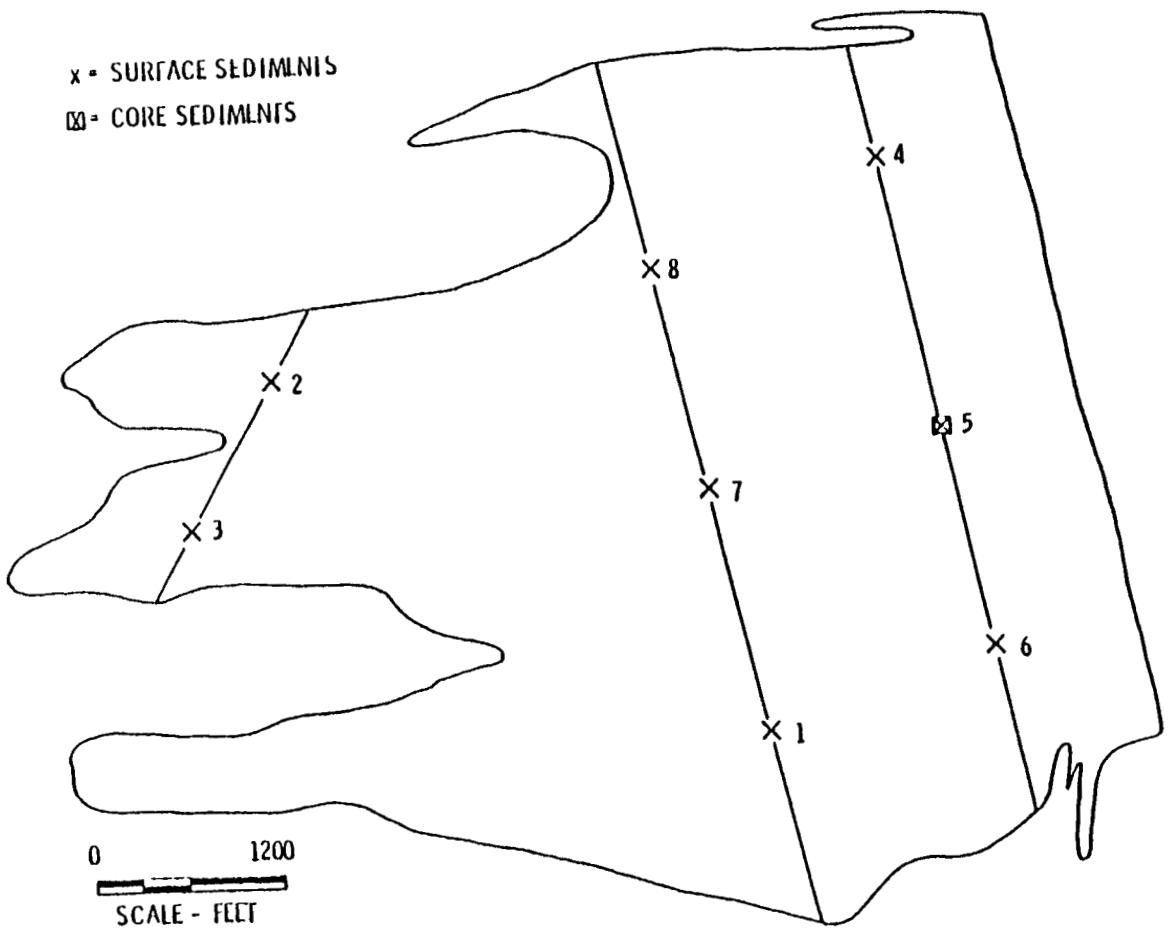

Figure 3 Sediment Sampling Stations at Standley Lake Reservoir

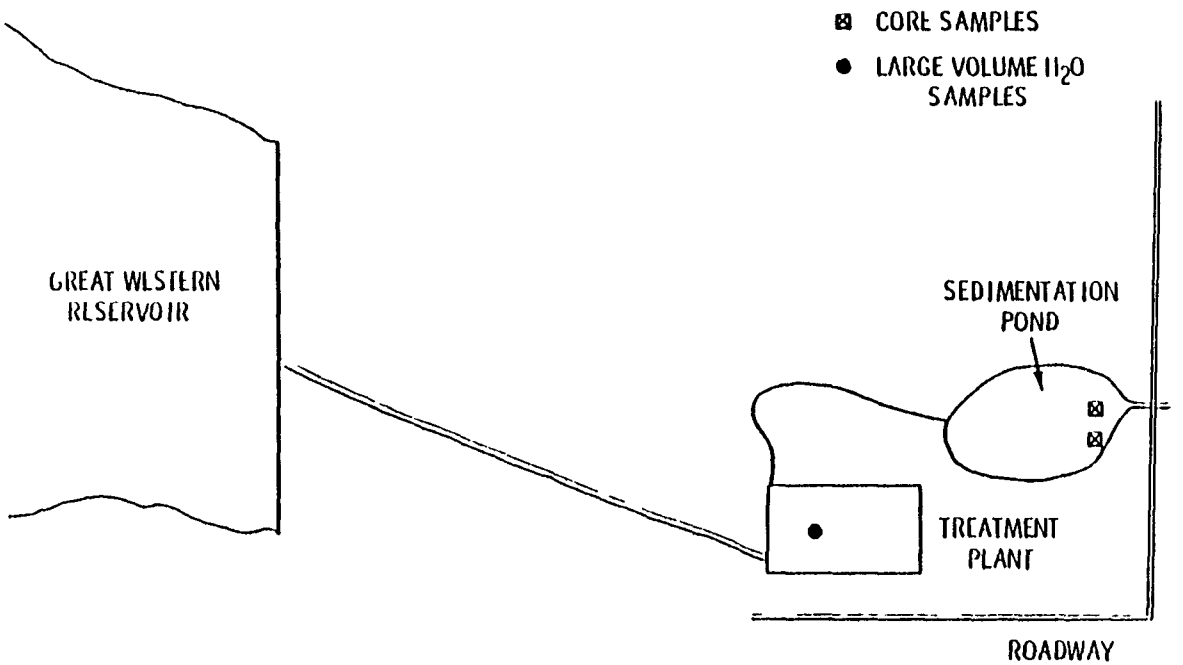

Figure 4 Large Volume Water and Sediment Sampling Location in the Vicinity of Broomfield Water Treatment Plant

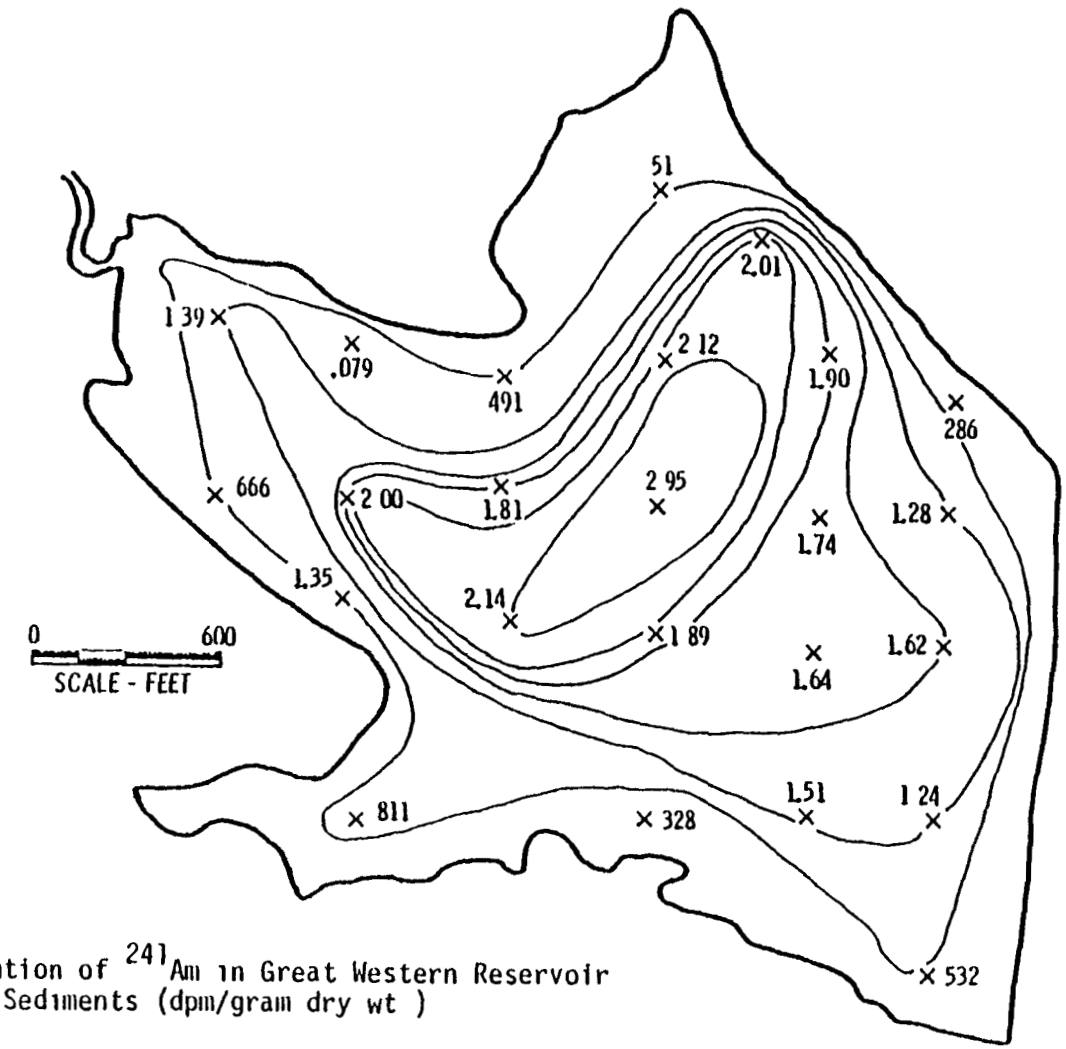

Figure 5 Distribution of ^{241}Am in Great Western Reservoir Surface Sediments (dpm/gram dry wt)

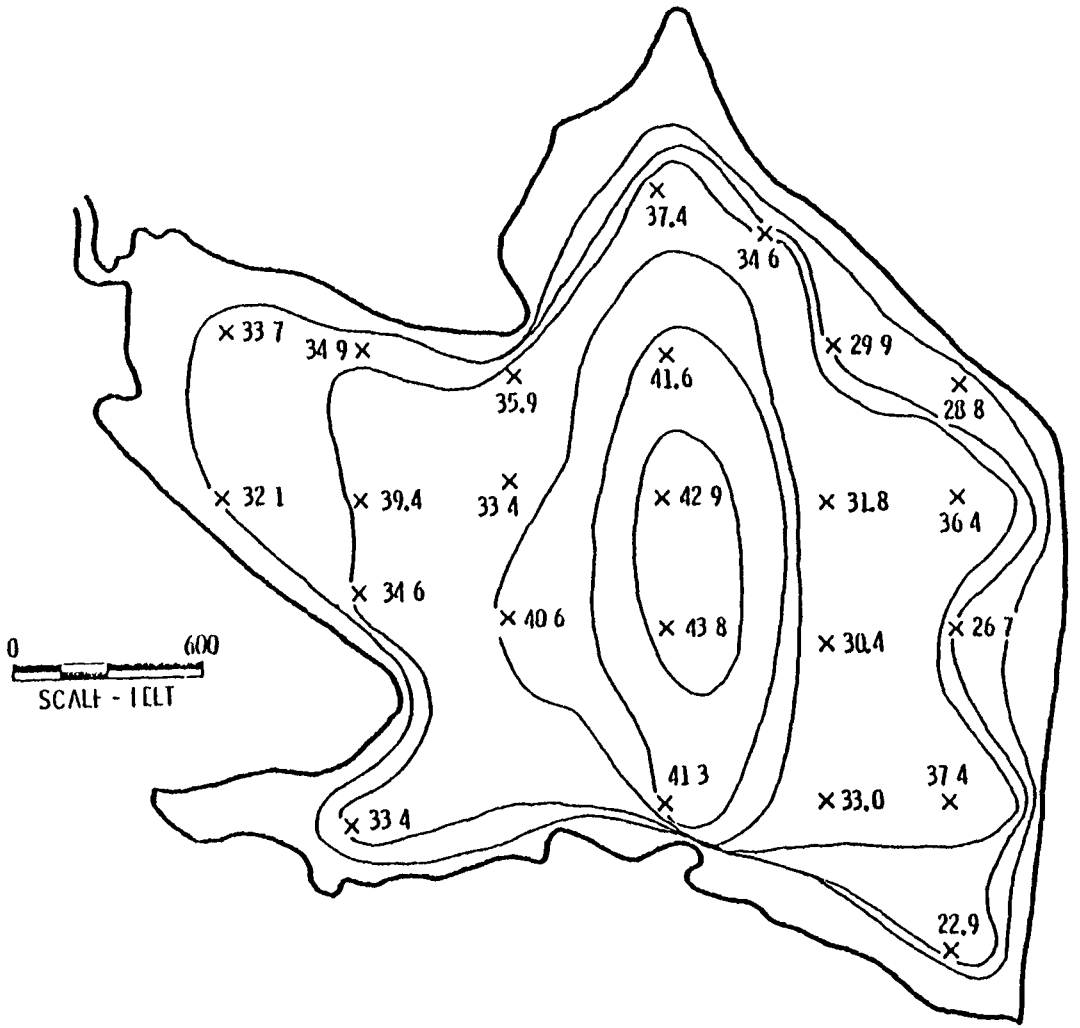

Figure 6 Distribution of ^{40}K in Great Western Reservoir Surface Sediments (dpm/g)

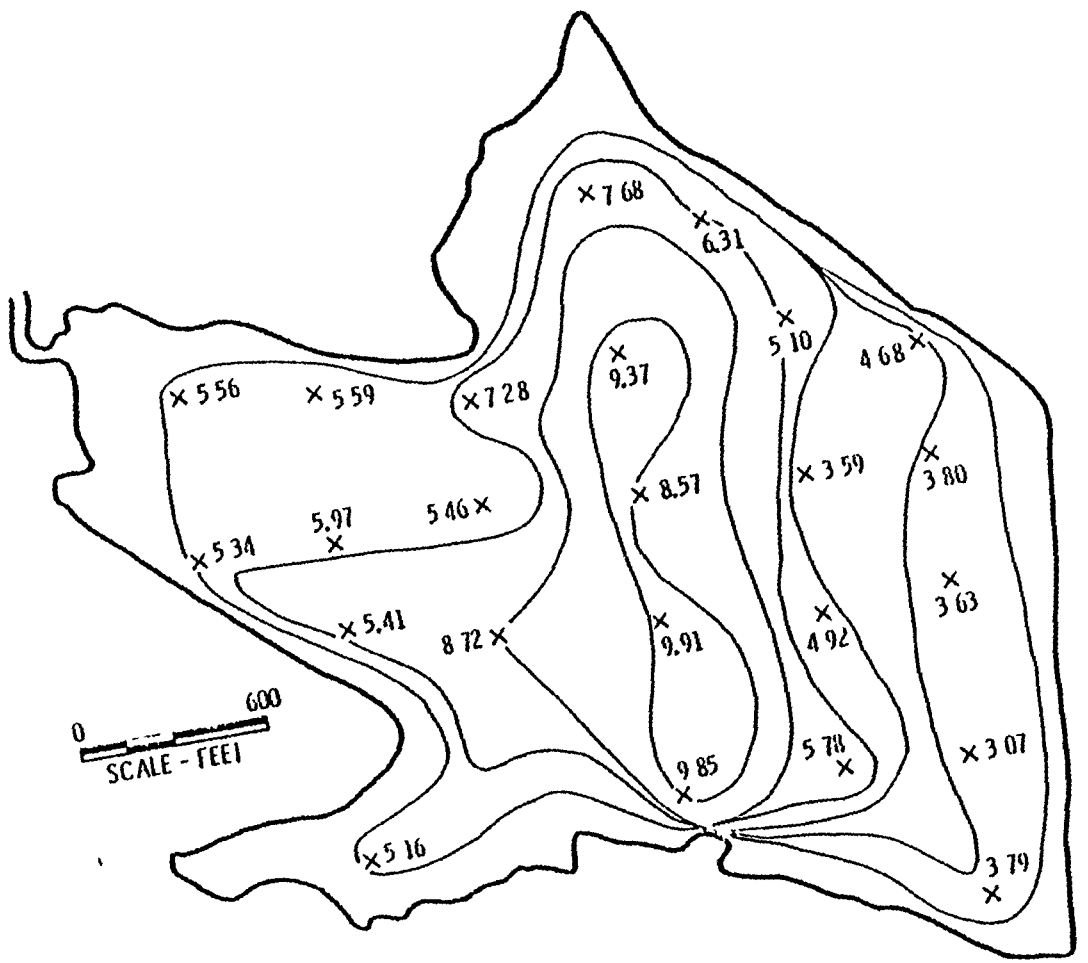

Figure 7 Distribution of ^{226}Ra in Great Western Reservoir Surface Sediments (dpm/gram)

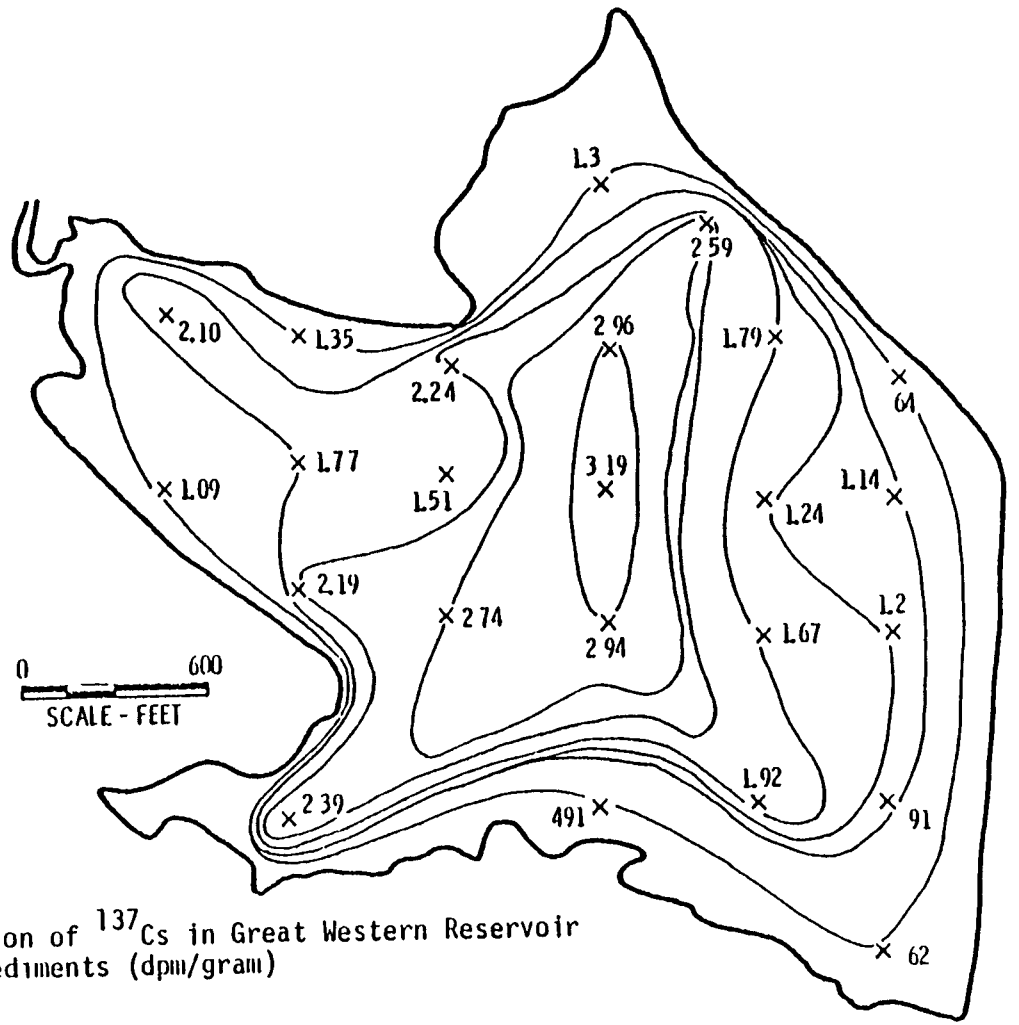

Figure 8 Distribution of ^{137}Cs in Great Western Reservoir Surface Sediments (dpm/gram)

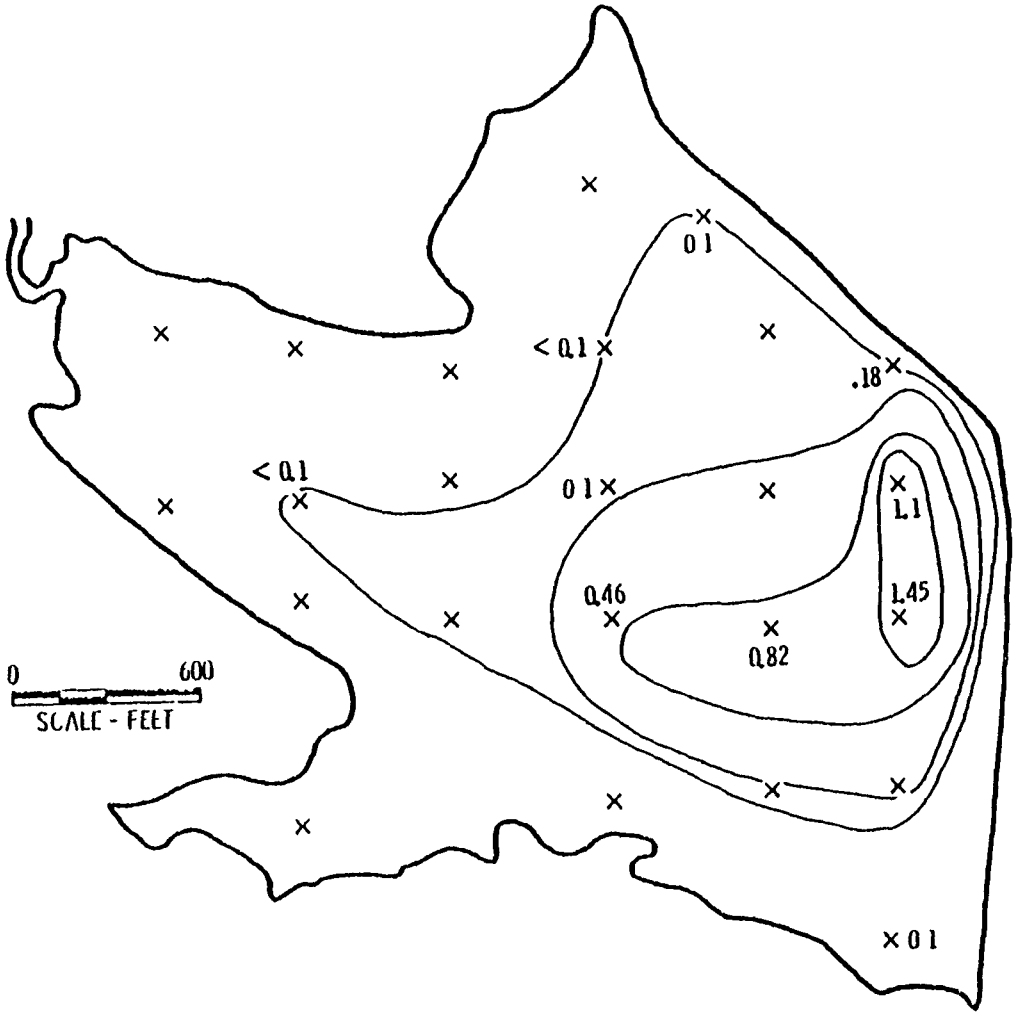

Figure 9 Deposition Rate of Sediments in Great Western Reservoir (inches/year)

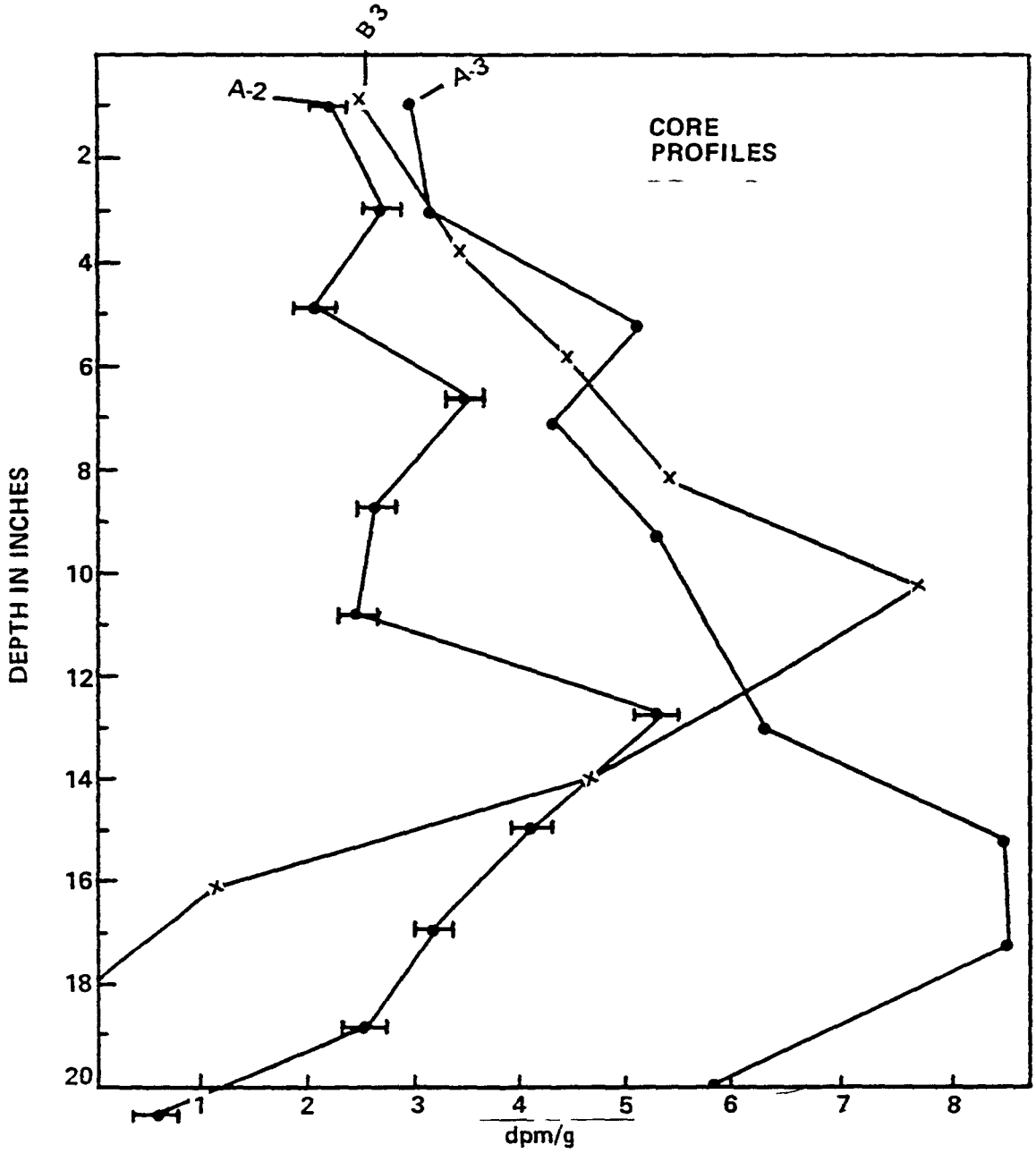

Figure 10 Depth Distribution of ^{137}Cs in Great Western Reservoir Sediments

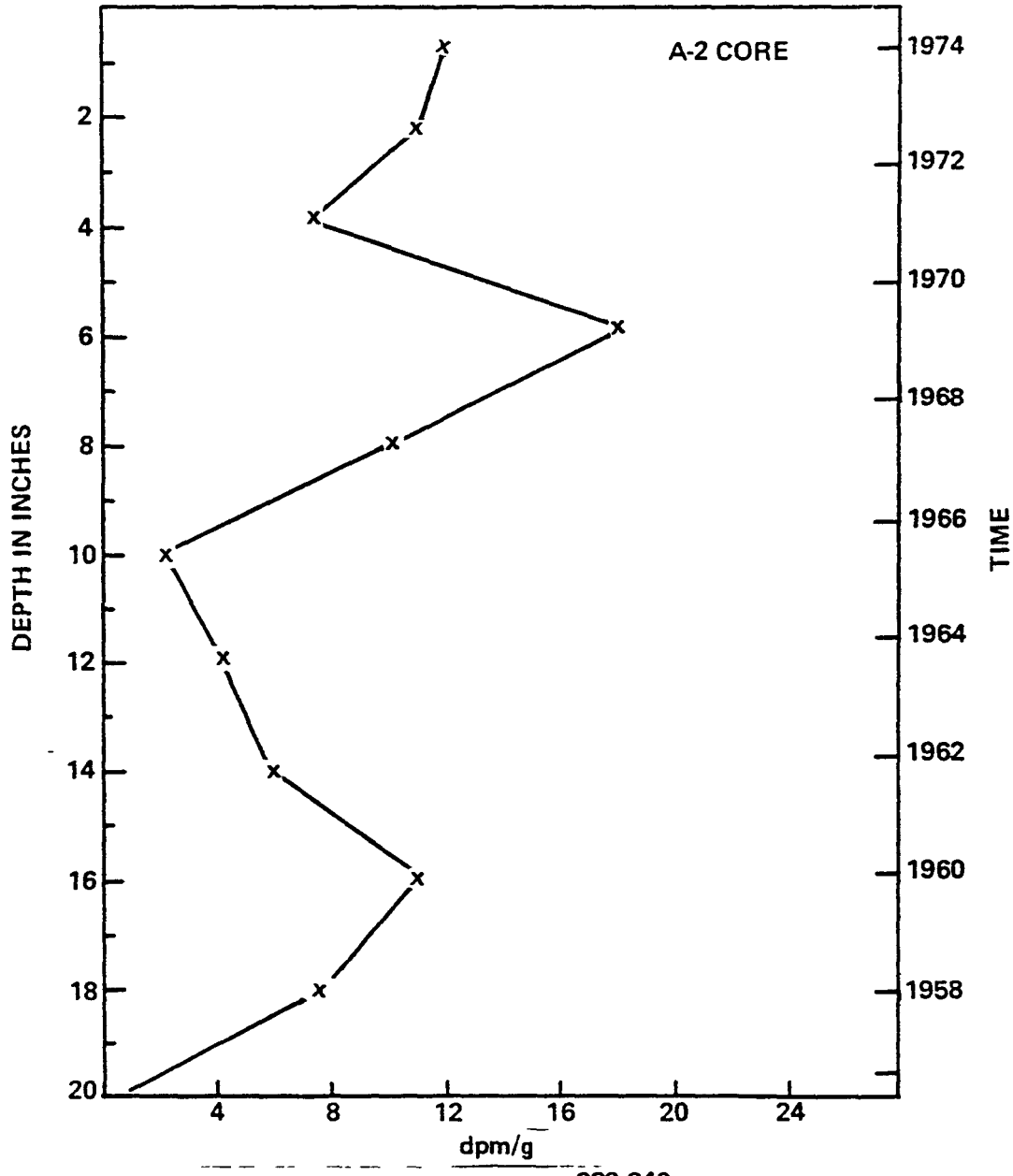

Figure 11 Depth Distribution of $^{239-240}Pu$ in Great Western Reservoir Sediments

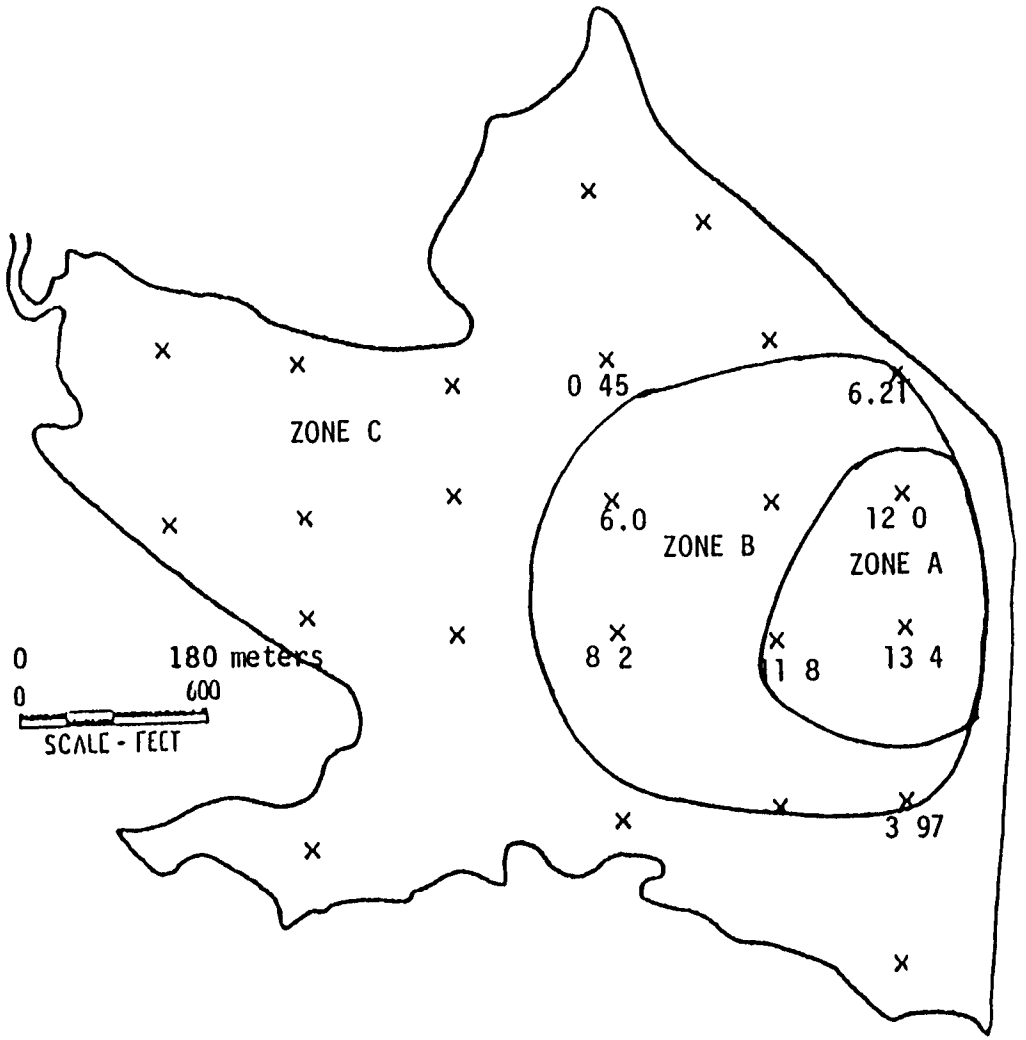

Figure 12 $^{239-240}$Pu Distribution in Surface (0-5 cm) Sediments in Great Western Reservoir and Zones Used for Estimating $^{239-240}$Pu Inventory in Sediments

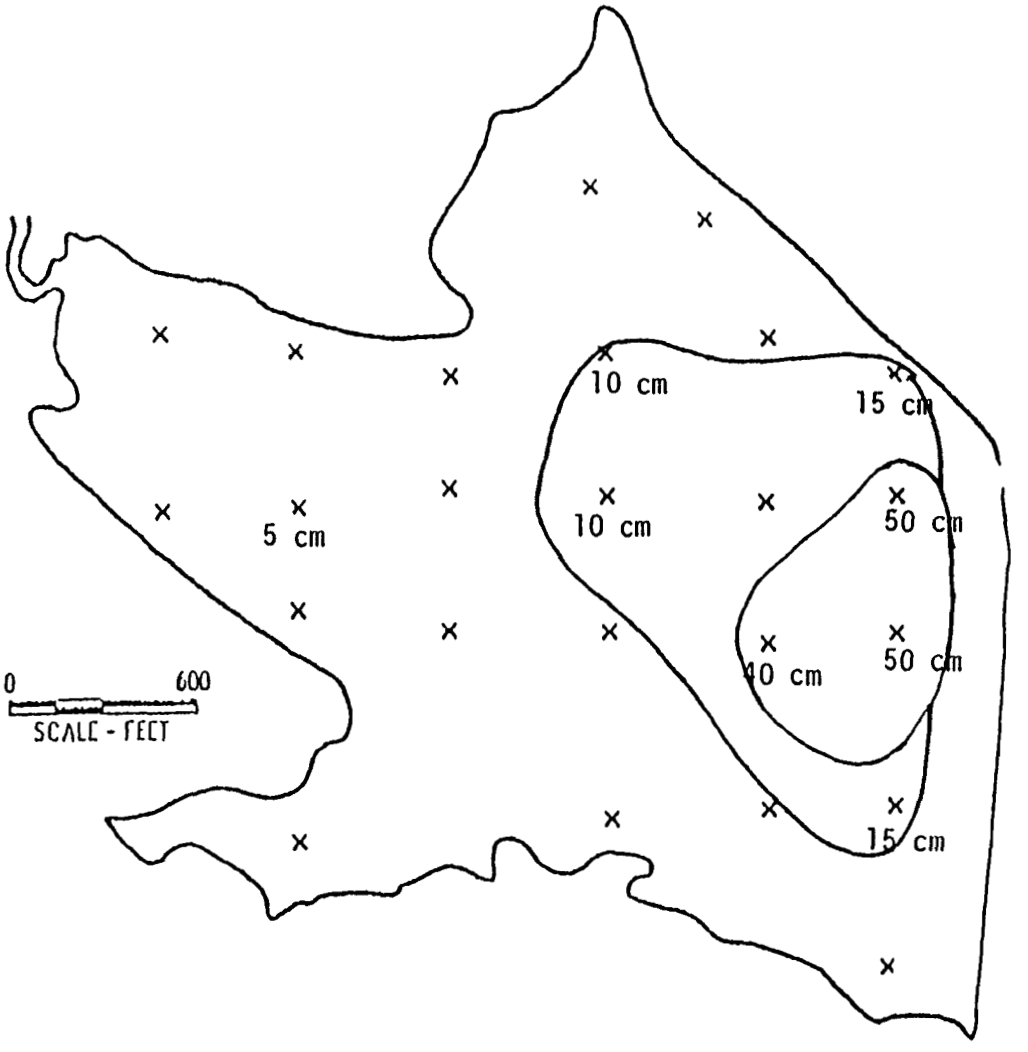

Figure 13 Approximate Depth of Sediments Deposited in Great Western Reservoir

February 27, 1980

John Harley, Director, EML

BATTELLE PNL REPORT "RADIONUCLIDE CONCENTRATIONS IN RESERVOIRS, STREAMS AND DOMESTIC WATERS NEAR THE ROCKY FLATS INSTALLATION"

I find no major technical problems with this work. It provides useful information on levels of transuranics and other radionuclides in the water systems near the Plant The study, which was conducted six years ago, deals mainly with Great Western Reservoir which receives some of the waste liquid discharge from the Plant. It is therefore difficult to distinguish that fraction of the plutonium found in sediment which was deposited following resuspension from the barrel storage area. Only the dated core segments from Great Western provided a history of plutonium contamination and both peak periods (1968-69 and 1959-64) were attributed by the authors to controlled water-borne releases.

Unfortunately, Standley Lake which contains Plant plutonium that arrived primarily by the airborne route, was not sampled as intensively. In fact, the single core taken showed no depth structure in the plutonium data according to the text In fact the plutonium data for the core segments are not presented and table 34 indicates plutonium was not measured. The core was taken in the same area of the Lake as the one WHOI took for us in 1976, but our core was 50 cm long while the PNL core was only 38 cm Assuming the sedimentation rates were similar, the PNL core would have missed the 1963-64 fallout peak. Neither this PNL study nor ours in 1976, however, answers the question of whether there was an airborne release from the Plant prior to that which started around 1966 and peaked in 1968-69

WHOI might feel the need to criticize the coring and preservation methods (e g. freezing before sectioning) used by PNL but I do not see important problems here.

DOCUMENT D-6

"Time Pattern of Off-Site Plutonium Contamination From Rocky Flats Plant by Lake Sediment Analyses"
(1978)

by

U S Department of Energy

TIME PATTERN OF OFF-SITE PLUTONIUM CONTAMINATION FROM ROCKY FLATS PLANT BY LAKE SEDIMENT ANALYSIS

L P Hardy, EML
H D Livingston, WHOI*
J C Burke, WHOI*
H I Volchok, EML

ABSTRACT

A 50 cm sediment core taken in 1976 from Studley Lake 7 km east of the Rocky Flats Plant, was sectioned into 1 cm segments which were analyzed for ^{137}Cs and transuranic radionuclides. Two independent time lines were developed based upon ^{137}Cs and transuranic peaks representing the 1963 fallout maximum and a high ^{238}Pu to $^{239,240}Pu$ ratio indicating the onset of fallout from the SNAP-9A satellite. The two time lines were identical making it possible to date the core over a 14 year period. A peak in transuranic concentrations occurring in late 1969 which was attributable to contamination from the Rocky Flats Plant. From mass isotopic analysis of plutonium isotopes in selected core segments the Rocky Flats and global fallout plutonium were differentiated making it possible to estimate that 18 nCi $^{239,240}Pu$ per m^2 from Rocky Flats had accumulated in the sediment. Although this amount represented inputs by both direct deposition of initially airborne material and soil erosion within the watershed, the amount in the sediment through 1970 is reasonable when compared to the plutonium in soil isopleths developed in 1973.

Introduction

The Rocky Flats Plant in Golden, Colorado is a Government-owned contractor operated facility which is part of a nationwide nuclear weapons production complex. A portion of the Plant is involved in plutonium processing and waste treatment. As a temporary measure beginning in 1958, drums containing cutting oil contaminated with plutonium were placed in open storage at the southeast corner of the plant[1]. By 1964 deterioration of some drums had caused the release of oil to the ground surface where plutonium became available for re-entrainment and redistribution by the wind. Following

* Woods Hole Oceanographic Institution, Woods Hole, Mass

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a major fire in 1969 in one of the plutonium handling facilities, Dr. E. A. Martell of the Colorado Committee for Environmental Information reported finding plutonium in soils on adjacent public and private lands[2]. In 1970, the Environmental Measurements Laboratory (EML, (formerly the Health and Safety Laboratory), employing sampling and analysis techniques developed during studies of world-wide fallout from nuclear testing, investigated soil contamination around Rocky Flats and the outlying areas[3]. The distribution of the total measured plutonium, shown in Figure 1, as well as meteorological considerations, identified the barrel storage area as the source of the contamination. The body of water at the center of this figure is Standley Lake, a reservoir primarily serving the community of Westminster.

In recent years a number of investigations have demonstrated that, in areas with high rates of sedimentation, sediment cores can provide a pollution history of an area[1-9], whereas soil samples, represent only the accumulated deposit of airborne debris[10]. Since Standley Lake lies between the 10 and 20 nCi per m^2 plutonium isopleths in Figure 1, examination of the sediment could provide a time pattern of plutonium contamination from the Rocky Flats Plant. Radioactivity measurements of sediment core sections provide information which can be used to estimate the time period over which each segment was deposited. Cesium-137 and transuranics from nuclear tests in the atmosphere cover the period from about 1954 to the present while lead-210, a naturally occurring radioisotope which is present in the atmosphere as a result of the radioactive decay of uranium in the earth's crust, can be used for dating over the last 100 years.

Methods

On August 25, 1970, one of us (C.L.) collected two sediment cores from the center of Standley Lake at a water depth of about 20 m. A 21 cm diameter barrel coring device equipped with a sphincter core retainer was used[11]. After siphoning off water from above the sediment water interface, a piston was placed in the barrel on top of the sediment column and the entire device was inverted. The core was then extruded from the bottom end in two cm segments. During the extrusion of the sediment, material in the nose cone and around the outer 1 cm edge of the core, was discarded. Both cores, which were composed of black oxidized mud, were soft and fluffy throughout their entire lengths[12].

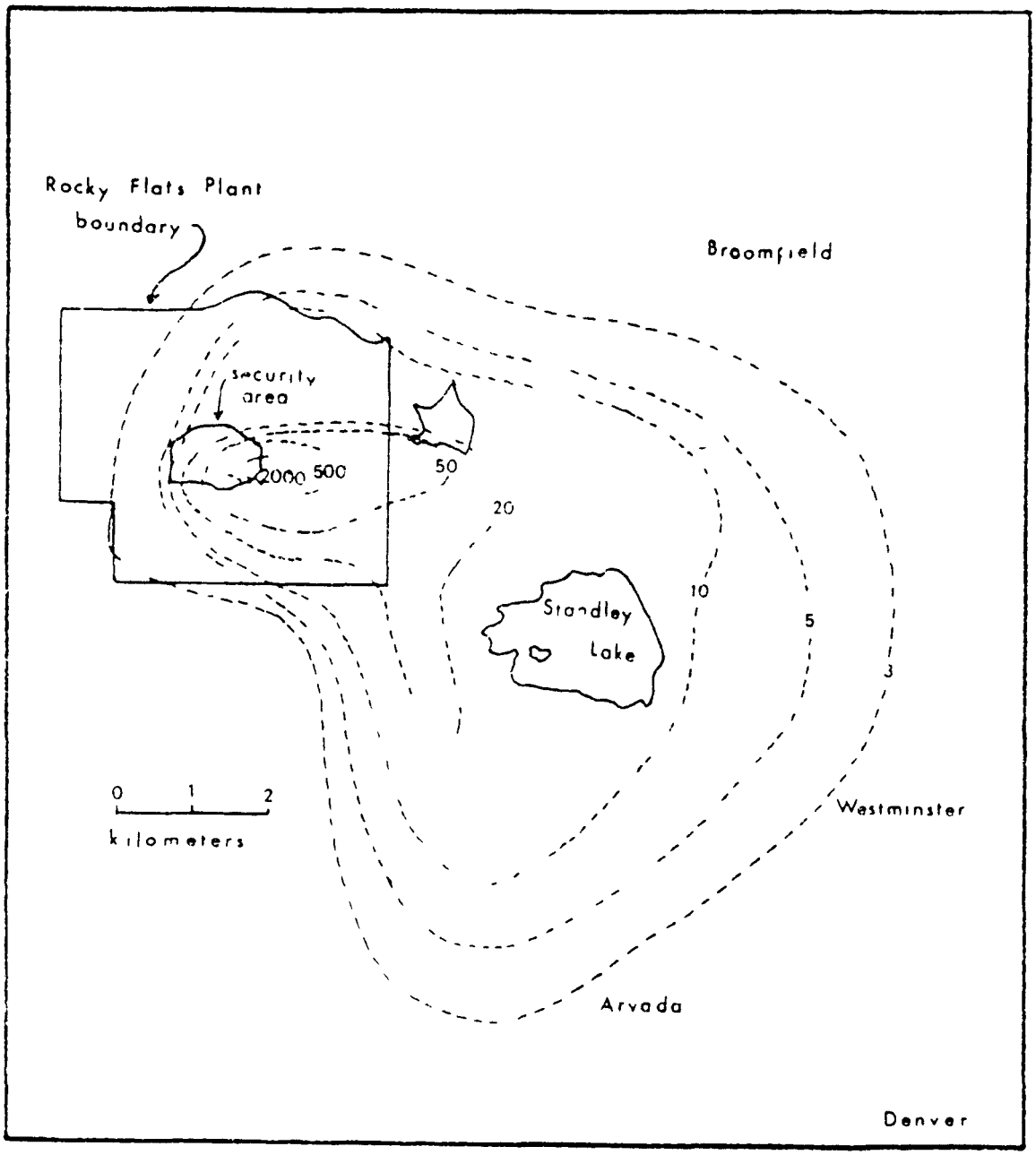


Figure 1 Plutonium-239, 240 contours around Rocky Flats, based on analyses of soil samples collected in 1970 (see ref 3) Contours in nCi per m^2

Twigs and other biological debris were also present throughout. The cores were 50 and 36 cm in length.

The core sections were sent to EML where they were homogenized by hand stirring with glass rods. Ten gram aliquots were dried to constant weight to determine the wet to dry weight ratio. Aluminum cans (90 cm^3) were filled with the wet sediment and sealed for direct gamma radiation counting. Approximately 100 gram aliquots of the wet sediment from the 50 cm core were sent to the Woods Hole Oceanographic Institution and to EPE-Environmental Analysis Laboratories in Richmond, California, under contract to EML, for radiochemical analyses.

The sediment sections were gamma counted for ^{137}Cs at EML using a germanium (lithium drifted) diode spectrometer. Aliquots sent to the WHOI were analyzed for ^{137}Cs by a radiochemical method[13].

A set of analyses was carried out to identify Rocky Flats Plant debris in the sediment core. This involved mass spectrometry of the plutonium fractions for 12 of the core segments. It has been shown that the mass isotopic composition of plutonium from global fallout and from the Rocky Flats Plant are markedly different[14,15]. The ^{240}Pu to ^{239}Pu mass ratio of plutonium used at the Rocky Flats Plant is 0.05 ± 0.01 whereas this ratio is 0.18 ± 0.01 for accumulated global fallout. In this situation a mixture of these two sources can be resolved by the following equation[16]

$$\frac{(^{239}Pu \text{ activity})_{gf}}{(^{240}Pu \text{ activity})_{gf}} = \frac{(R_f - R_{samp})}{(R_{samp} - R_{gf})} \times \frac{(1 + 3.6\,R_{gf})}{(1 + 3.6\,R_f)} \qquad (1)$$

where R_f = 0.05, the atom ratio of Rocky Flats plutonium

R_{gf} = 0.18, the global fallout atom ratio

R_{samp} = individual sample atom ratio

Mass spectrometric analyses of the electroplated discs containing the radiochemically separated plutonium fractions were performed at the Knolls Atomic Power Laboratory to determine the atom ratios of ^{240}Pu to ^{239}Pu.

Results

The ^{137}Cs data are shown in Table 1 and averaged EML and WHOI values for the 50 cm core plotted in Figure 2. The agreement between the two cores is quite remarkable and supports our

Table 1

^{137}Cs in Standley Lake Core Sections

Depth increment (cm)	dpm per kg Dry Sediment			
	Core - 1			Core - 2
		WHOI		
	LMI	1st analysis	2nd analysis	LML
0 - 2	1600 ± 100	1390 ±10		1500 ± 200
2 - 4	1100 ± 100			1200 ± 100
4 - 6	2100 ± 100	1910 ±12		2000 ± 100
6 - 8	2300 ± 100	2530 ±20		2100 ± 200
8-10	2900 ± 100	2650 ±20	3060 ±40	2800 ± 100
10 - 12	2500 ± 200			2900 ± 100
12 - 14	3200 ± 200	2810 ±13		2900 ± 100
14 - 16	2900 ± 200			2300 ± 100
16 - 18	2900 ± 200	2900 ±14		3600 ± 100
18 - 20	2800 ± 300			3300 ± 200
20 - 22	3500 ± 200	3540 ±20		4100 ± 100
22 - 24	3200 ± 200			3400 ± 100
24 - 26	3400 ± 200	3580 ±20	3910 ±30	3700 ± 100
26 - 28	3900 ± 200			3800 ± 100
28 - 30	4100 ± 200	*2193 ±12	4040 ±25	4000 ± 100
30 - 32	3900 ± 100			4500 ± 100
32 - 34	4100 ± 200	3670 ±20		3900 ± 200
34 - 36	4100 ± 100			5700 ± 200
36 - 38	5000 ± 200	*3106 ±12	5560 ±30	
38 - 40	5100 ± 200	4530 ±10	5430 ±20	
40 - 42	5500 ± 300	4908 ± 32	6090 ± 30	
42 - 44	6400 ± 300	5926 ±16	6810 ±25	
44 - 46	4800 ± 200	5328 ±15		
46 - 48	4600 ± 200			
48 - 50	3200 ± 200	3036 ±10		

* Data suspect - not used in averaging

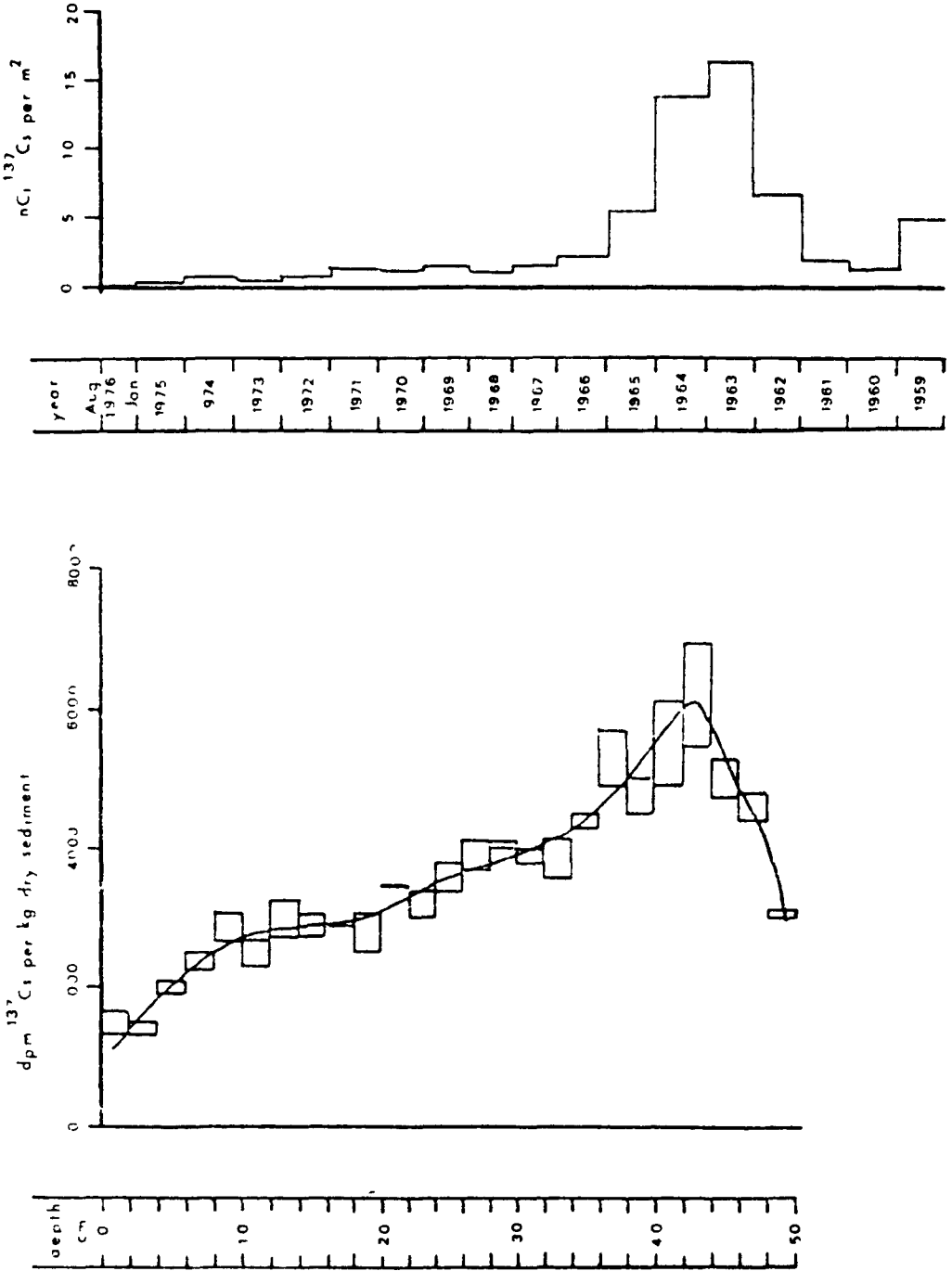


Figure 2 Depth distribution of ^{137}Cs in Standley Lake sediment compared with annual ^{137}Cs deposition in the Denver area

assertion that the sampling is representative of the lake sediment in the center of the lake. Since 1959 the EML has maintained a fallout collection station near Denver's Stapleton Airport[17]. Strontium-90 deposition measured in monthly samples at that station were converted to ^{137}Cs, using the well established ^{137}Cs to ^{90}Sr ratio in global fallout of 1.5[18], and annual summations through August 1976 plotted in Figure 2. The transuranic data are given in Table 2 and averages plotted in Figure 3 along with the ^{137}Cs curve transposed from Figure 2. Activity ratios based on the averaged transuranic and ^{137}Cs concentrations are tabulated in Table 3 and plotted in Figure 4. Only the more precise WPOI ^{238}Pu data are plotted. The curves in Figures 3 and 4 are intended to represent the most reasonable trends of the data considering the analytical errors associated with the measurements and the interlaboratory data spread.

Recovery operations at the leaking barrel storage area began in 1967 at the Rocky Flats Plant. Plots of total long-lived alpha activity in on-site aerosol samples collected and analyzed by the Dow Chemical Co.[19] are reproduced in Figure 5 and show a maximum in January 1969. An asphalt pad was placed over the barrel storage area in 1969 to reduce further re-entrainment of plutonium contaminated particles.

The mass spectrometric analyses provided the ^{240}Pu and ^{239}Pu atom ratios given in Table 4. Using the relationship [1] described earlier, the contributions of plutonium from fallout and from the Rocky Flats Plant were calculated for each sample. The Rocky Flats Plant component in each sample was expressed as a percentage of the total plutonium activity and is also tabulated in the last column of Table 4.

The concentration data for each sediment section were converted to activity per unit area, and the sediment sections summed to obtain a deposition inventory over the 11 year period. Basic weight data associated with the core segments are given in Table 5. Since the concentration data are reported in units of dry weight, the conversion to activity per unit of area can be carried out from the values of dry weight per unit of area in the last column of Table 5. This was done for ^{137}Cs and $^{239,240}Pu$ using the hand-drawn curves through the data points of Figure 3 and the results are given in Table 6. Since the data represent consecutive core segments the summation is the total activity of the nuclide per unit area of the core.

Table 2

Transuranic Nuclides in Standley Lake Core Sections

Depth increment (cm)	dpm per kg Dry Sediment							
	^{239,240}Pu			^{238}Pu			^{241}Am	
	LFE	WHOI 1st analysis	WHOI 2nd analysis	LFE	WHOI 1st analysis	WHOI 2nd analysis	LFE	WHOI
0 - 2	120 ± 10	133 ± 4		3 ± 3	3.0 ± 0.3		17 ± 3	20 ± 1
2 - 4	110 ± 10			8 ± 5			16 ± 3	
4 - 6	200 ± 10	206 ± 6		7 ± 4	5.2 ± 0.5		45 ± 8	28 ± 1
6 - 8	300 ± 10	230 ± 9			7.7 ± 1.1			
8 - 10	320 ± 20	*550 ± 15	220 ± 8	14 ± 4	*11.6 ± 0.9	5.8 ± 1.1	60 ± 5	
10 - 12	270 ± 10			9 ± 4			45 ± 4	
12 - 14	370 ± 20	362 ± 7		12 ± 4	8.8 ± 0.4		50 ± 4	49 ± 2
14 - 16	350 ± 20			8 ± 4			43 ± 4	
16 - 18	450 ± 20	425 ± 9		15 ± 1	10.2 ± 0.6		76 ± 8	
18 - 20	550 ± 30			12 ± 3			66 ± 7	
20 - 22	790 ± 40	767 ± 17		20 ± 4	18.1 ± 1.0		100 ± 10	111 ± 3
22 - 24	800 ± 10			17 ± 3			110 ± 10	
24 - 26	1200 ± 100	855 ± 22	1235 ± 40	21 ± 3	18.4 ± 1.2	23.7 ± 2.3	120 ± 10	113 ± 4
26 - 28	930 ± 20			19 ± 2			130 ± 14	
28 - 30	500 ± 60	493 ± 13	128 ± 13	13 ± 3	13.4 ± 0.9	10.6 ± 1.2	63 ± 9	68 ± 3
30 - 32	180 ± 10			8 ± 4			23 ± 6	
32 - 34	90 ± 10	74 ± 2		6 ± 3	4.9 ± 0.5		22 ± 6	17 ± 1
34 - 36	80 ± 10			3 ± 3			20 ± 6	
36 - 38	95 ± 10	99 ± 3	99 ± 3	6 ± 4	2.4 ± 0.3	*3.8 ± 0.6	24 ± 3	
38 - 40	120 ± 10	128 ± 3	115 ± 4	1 ± 2	2.7 ± 0.3	2.6 ± 0.5	28 ± 3	
40 - 42	140 ± 10	131 ± 10	130 ± 6	4 ± 2	3.3 ± 0.4	3.5 ± 0.8	36 ± 3	32 ± 2
42 - 44	160 ± 10	158 ± 5	157 ± 4	7 ± 4	4.3 ± 0.5	4.7 ± 0.5	32 ± 6	43 ± 2
44 - 46	140 ± 10	151 ± 4		4 ± 2	3.0 ± 0.4		26 ± 3	
46 - 48	100 ± 10			5 ± 2			6 ± 3	
48 - 50	90 ± 10	88 ± 2		3 ± 3	2.6 ± 0.3		20 ± 6	

* Data suspect - not used in averaging

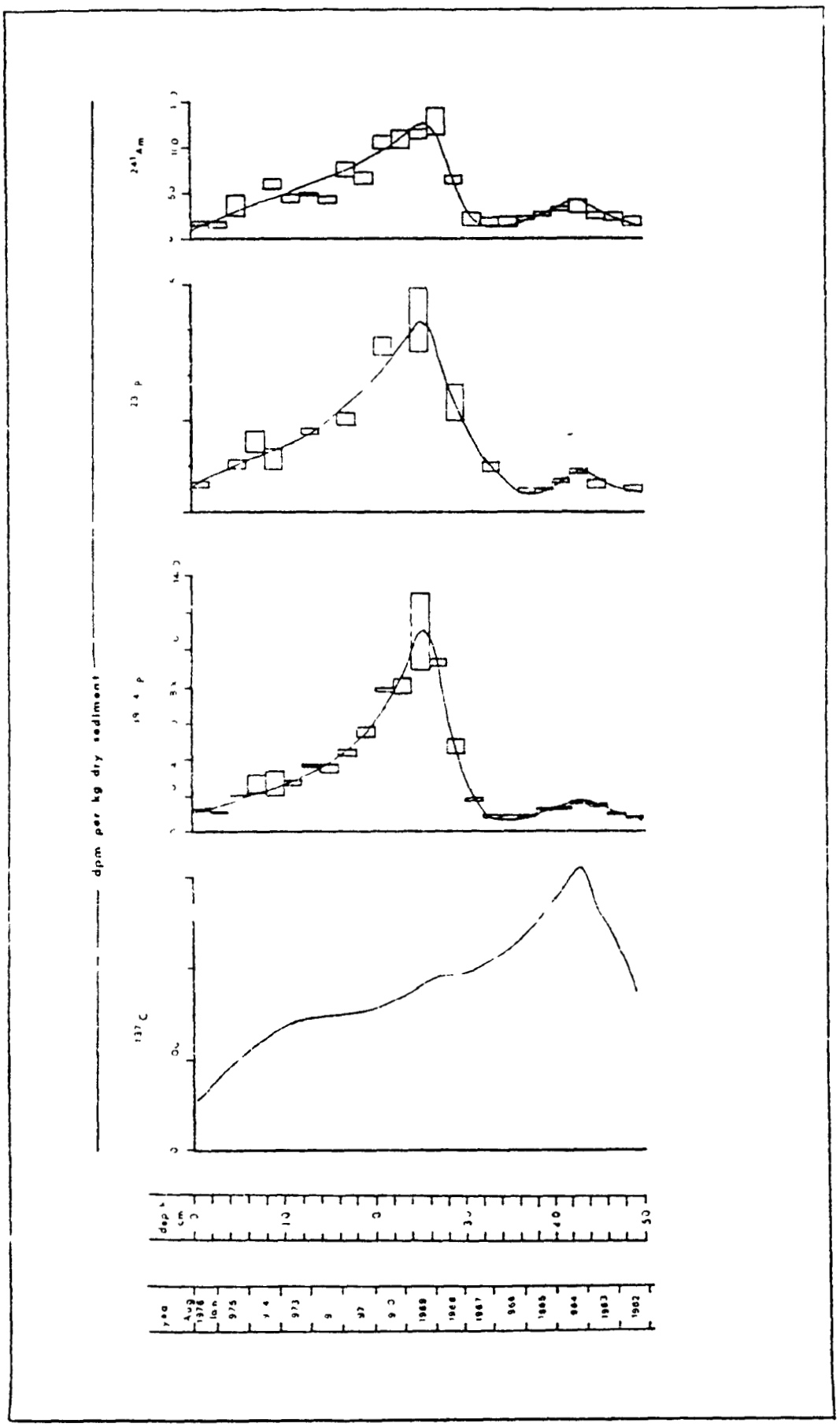
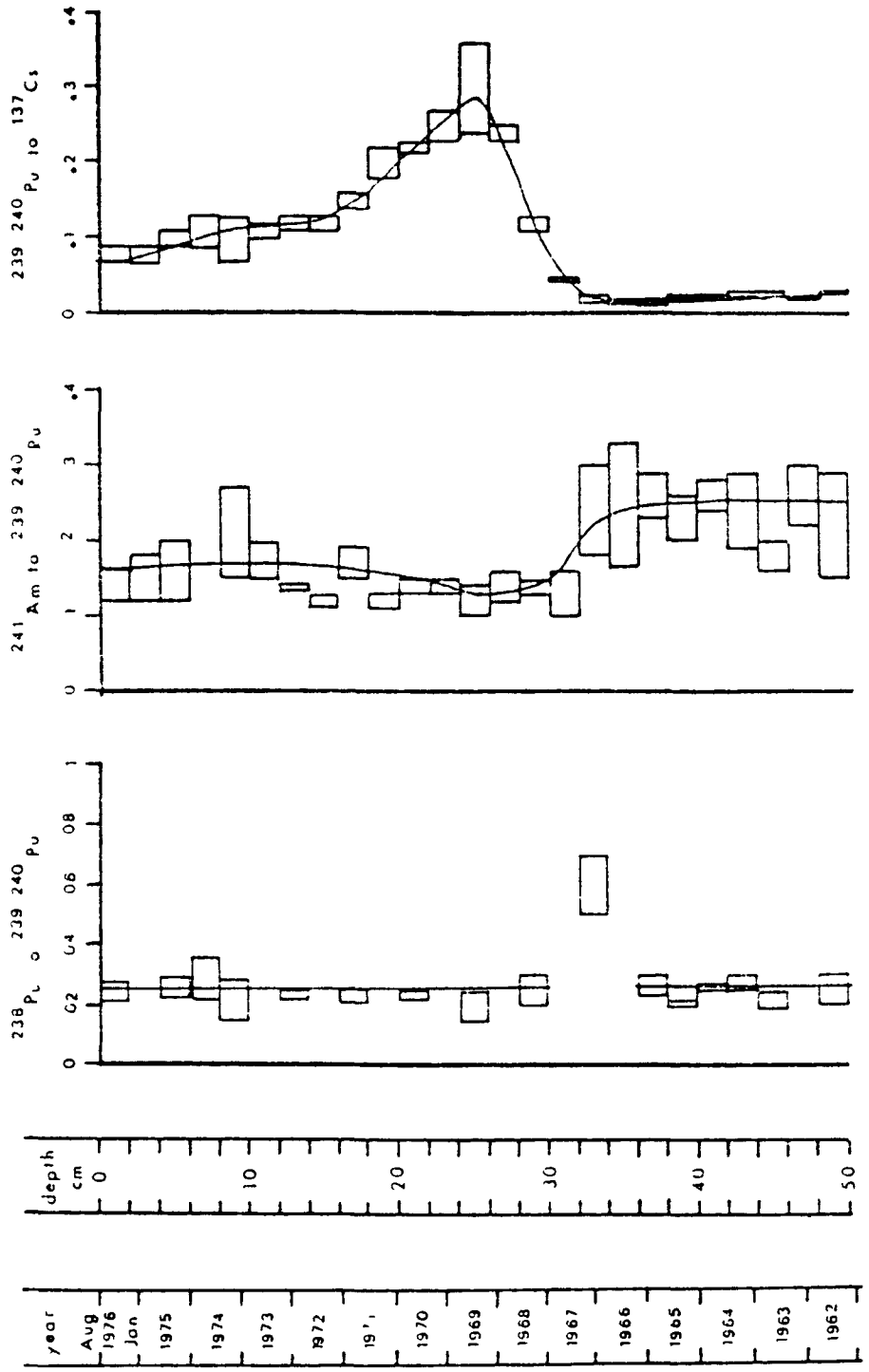


Figure 3 Depth distribution of ^{137}Cs, $^{239,240}Pu$ and ^{241}Am in Standley Lake sediment

Table 3

Activity Isotope Ratios for Standley Lake Core Sections

Depth increment (cm)	Ratio ^{238}Pu / $^{239,240}Pu$	Ratio ^{241}Am / $^{239,240}Pu$	Ratio $^{239,240}Pu$ / ^{137}Cs
0 - 2	0 021 ± 0 003	0 14 ± 0 02	0 08 ± 0 01
2 - 4		0 15 ± 0 03	0 08 ± 0 01
4 - 6	0 026 ± 0 003	0 16 ± 0 04	0 10 ± 0 01
6 - 8	0 029 ±0 007		0 11 ±0 02
8 - 10	0 021 ±0.007	0.21 ±0 06	0.10 ±0 03
10 - 12		0 17 ±0 02	0 11 ±0 01
12 - 14	0 024 ±0 001	0 137±0 004	0 12 ±0 01
14 - 16		0 12 ±0 01	0 12 ±0 01
16 - 18	0 023 ±0 002	0 17 ±0 02	0 15 ±0 01
18 - 20		0 12 ±0 01	0 20 ±0 02
20 - 22	0 023 ±0 001	0 14 ±0 01	0 221 ±0 005
22 - 24		0 14 ±0.01	0 25 ±0 02
24 - 26	0 019 ±0 005	0 12 ±0 02	0 30 ±0 06
26 - 28		0 14 ±0 02	0 24 ±0 01
28 - 30	0 025 ±0 005	0 14 ±0 01	0 12 ±0 01
30 - 32		0 13 ±0 03	0 046 ± 0 003
32 - 34	0 06 ±0 01	0 21 ±0 06	0 021 ± 0 003
34 - 36		0 25 ± 0 08	0 018 ±0 002
36 - 38	0 026 ±0 003	0 26 ±0 03	0 018 ±0 002
38 - 40	0 021 ±0.001	0 23 ±0.03	0 024 ±0 002
40 - 42	0 026 ±0 001	0 26 ±0 02	0 024 ± 0 003
42 - 44	0 028 ±0 002	0 24 ±0 05	0 026 ±0 003
44 - 46	0 021 ±0.003	0.18 ±0.02	0.029 ±0 002
46 - 48		0 26 ±0.04	0.022 ± 0.002
48 - 50	0 029 ±0.003	0.22 ±0.07	0.029 ± 0.001


$^{239\ 240}Pu$ to ^{137}Cs
0
.1
.2
.3
.4
^{241}Am to $^{239\ 240}Pu$
0
1
2
3
.4
^{238}Pu to $^{239\ 240}Pu$
0
.2
.4
.6
.8
1
depth cm
0
10
20
30
40
50
year
Aug 1976
Jan 1975
1974
1973
1972
1971
1970
1969
1968
1967
1966
1965
1964
1963
1962

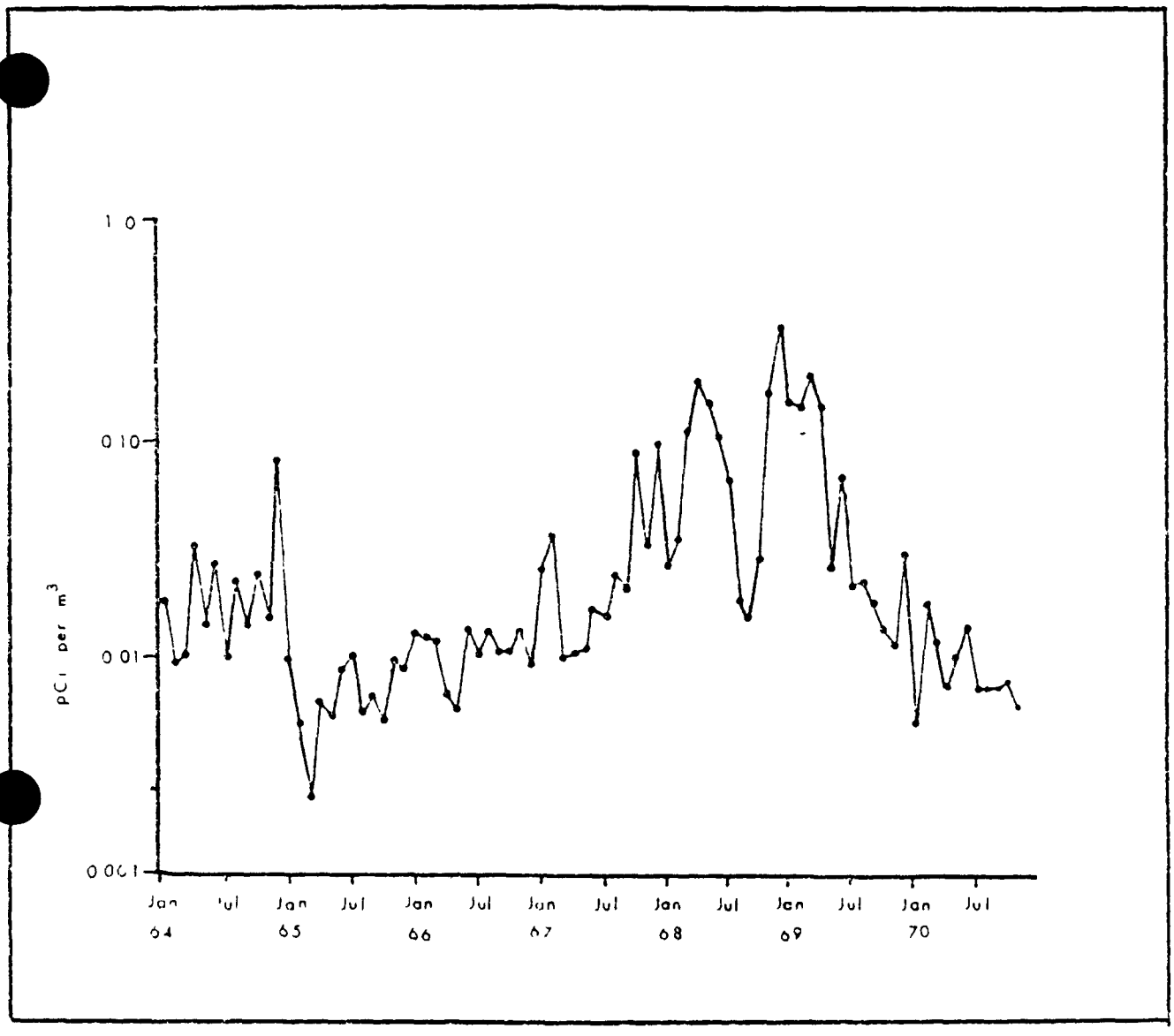


Figure 5 Total long-lived alpha activity in air at station S-8, Rocky Flats Plant (see ref 19)

Table 4

Mass Ratio, ^{240}Pu to ^{239}Pu, in Standley Lake Core Sections

Depth increment (cm)	$^{240}Pu / ^{239}Pu$	% of total Pu from Rocky Flats
0 - 2	0.077 ± 0 004	74
8 - 10	0 064 ± 0 003	86
12 - 14	0 063 ± 0 003	87
16 - 18	0 069 ± 0 003	80
20 - 22	0 060 ± 0 003	90
24 - 26	0 060 ± 0 003	90
26 - 28	0 062 ± 0 003	88
28 - 30	0 080 ± 0 005	71
30 - 32	0 102 ± 0 005	52
34 - 36	0 154 ± 0 008	16
38 - 40	0 176 ± 0 009	2
42 - 44	0 188 ± 0 009	0

Table 5

Density and Water Content of Standley Lake Core Sections

Depth increment (cm)	g Wet sediment per cm^3	% H_2O	g Dry sediment per cm^2 *
0 - 2	1 19	70 2	0 71
2 - 4	1 23	61 4	0 95
4 - 6	1 20	73.2	0 64
6 - 8	1 15	72 9	0 62
8 - 10	1 16	76.5	0 54
10 - 12	1 19	74.6	0 60
12 - 14	1 18	75.1	0 59
14 - 16	1.21	71 1	0 70
16 - 18	1 19	74.7	0 60
18 - 20	1 19	71.3	0 68
20 - 22	1 20	73.7	0 63
22 - 24	1 19	68 4	0 75
24 - 26	1 19	69.8	0 72
26 - 28	1.21	69.1	0 75
28 - 30	1 19	69 9	0 72
30 - 32	1 21	70.0	0.73
32 - 34	1 20	66.1	0 81
34 - 36	1.22	63 8	0.83
36 - 38	1 28	60	1 02
38 - 40	1.29	57 5	1.10
40 - 42	1 23	64 2	0.88
42 - 44	1 26	66.5	0 84
44 - 46	1 24	66 0	0.84
46 - 48	1.23	67.0	0 81
48 - 50	1 26	65.8	0.86

* Per 2 cm thick segment

Table 6

Inventories of Radionuclides in Standley Lake Sediment Core

Depth increment (cm)	nCi per m^2	
	^{137}Cs	$^{239,240}Pu$
0 - 2	3 8	0 31
2 - 4	6 8	0 81
4 - 6	5 8	0 49
6 - 8	6 4	0 56
8 - 10	6 3	0 58
10 - 12	7 6	0 74
12 - 14	7 7	0 86
14 - 16	9 4	1 18
16 - 18	8 1	1 22
18 - 20	9 3	1 68
20 - 22	9 1	1 93
22 - 24	11 5	2 96
24 - 26	11 7	3 57
26 - 28	12 8	2 87
28 - 30	12 6	1 46
30 - 32	13 1	0 66
32 - 34	15 3	0 27
34 - 36	16 4	0 22
36 - 38	22 0	0 37
38 - 40	26 3	0 59
40 - 42	22 8	0 59
42 - 44	23 4	0 06
44 - 46	20 0	0.57
46 - 48	17 0	0 38
48 - 50	13 6	0.29
Σ	318 8	25 8

Development of Time Scale

A record of sediment deposition can be reconstructed from examination of the data in Tables 1 - 3 and Figures 2 - 4. It can be seen that a maximum in both ^{137}Cs and transuranic nuclides occurs toward the bottom of the 50 cm core, in the 42-44 cm section. The ^{137}Cs decreases fairly smoothly from this depth to the sediment - water interface while the transuranic data show a much larger second maximum in the 21-26 cm section. The argument is advanced that

1. The deep ^{137}Cs and transuranic maxima represent the record in the sediment of the 1963 nuclear fallout maximum which occurred after the 1961-62 period of intensive nuclear testing by the United States and the Soviet Union.
2. The shallower and larger transuranic maximum represents the sediment record of particles contaminated with material originating from the Rocky Flats Plant.

This interpretation is supported by a variety of isotopic ratio data. The top 32 cm of the sediment are characterized by the ratio of ^{241}Am to $^{239,240}Pu$ of about 0.15, whereas the deeper sections average 0.21. These ratios have been shown respectively to characterize soil contaminated with Rocky Flats debris[20], and global fallout debris from the 1961-62 nuclear test series[21]. The $^{239,240}Pu$ to ^{137}Cs ratio rises from values between 0.02 and 0.03 to a peak of 0.[illegible] between 1962-63 corresponding to the assumed distribution pattern of Rocky Flats debris in the sediment. The ^{240}Pu to ^{239}Pu mass ratio data in Table 1 in the sections of the core deeper than 31 cm ranges from 0.17 to 0.19 and are likewise characteristic of the ratio (0.18 ± 0.01) measured in accumulated global fallout[11]. On the other hand, the lower ratios, 0.06 - 0.10, measured in the top 2 cm of the core are consistent with a mixture of particles containing Rocky Flats plutonium (mass ratio of ^{240}Pu to ^{239}Pu = 0.05 ± 0.01) with particles containing plutonium from global fallout, resolvable as described earlier. One further piece of isotopic evidence supports these characterizations. The failure of the ^{238}Pu powered SNAP-9A satellite in 1964 over the Southern Hemisphere led to a Northern Hemisphere mid-latitude maximum in the activity ratio ^{238}Pu to $^{239,240}Pu$ in fallout around April 1967[22,23]. The more precise WHOI ^{238}Pu to $^{239,240}Pu$ ratios in Table 3 lie between 0.02 and 0.03 except for the 32-34 cm section where its 0.06 ± 0.01 value is significantly higher than the other ratios. This high ratio is taken to represent the first indication in the sediment record of the arrival

of SNAP-9A ^{238}Pu. We could not follow the SNAP-9A ^{238}Pu in the core because the subsequent sediment section contained an overwhelming amount of Rocky Flats ^{238}Pu which began depositing at this time. The ^{238}Pu to ^{239,240}Pu ratios of Rock Flats and global fallout nuclear test debris are quite similar, as expected[3, 25]. The time of the appearance of the SNAP-9A ^{238}Pu in the sediment record is taken to be the end of 1966, as this was six months after the earliest time when substantial amounts of SNAP-9A ^{238}Pu began to be recorded in the sediment[24]. It is assumed that sediment accumulation will be greatest in winter when precipitation is higher.

A time scale can then be constructed for the sediment core assuming that:

1. The middle of the 12-14 cm section corresponds to the end of 1963, the six months after the maximum fallout concentrations were observed.
2. The middle of the 32-34 cm section corresponds to the end of 1966, the six months after the first appearance of increased ^{238}Pu from SNAP-9A in fallout.

These time scales are almost identical suggesting an average sedimentation rate of 1.4 cm per year. This value was used to derive the time scales plotted in Figures 2, 3 and 4. As an independent check on this time scale, some of the 30 cm core segments were analyzed for total and supported ^{210}Pb. D. Elkins at the Atomic Energy Research Establishment in Harwell, England, also reported ^{210}Pb, though measurable, did not amount to a substantial fraction of the total ^{210}Pb and no obvious decrease in concentration was observed. These data were not interpretable, therefore, in terms of the depositional history of this sediment core.

The "Rocky Flats plutonium" peak in concentration maxima in the 24-26 cm section are then dated as corresponding to the year 1969. This date seems quite reasonable as it follows by about 6 months the maximum aerosol concentration of total long-lived alpha activity at the Rocky Flats site (Figure 5). Both the total alpha activities in the aerosols and the transuranic concentrations being deposited in the lake sediment, decreased from this time.

Inventories

Measurements of ^{137}Cs in 5 cm soil samples taken along the eastern boundary of Rocky Flats Plant in 1973 ranged from 85 to 110 nCi per m^2 [26]. Depth distribution studies of ^{137}Cs in soil carried out at RFP have shown that usually 95 percent or more of this radionuclide is in the top 5 cm[27]. From Table 6, the ^{137}Cs total of 319 nCi per m^2 in the sediment core is about three to four times higher than the values which represent the

accumulated deposition of global fallout. This sediment core represents only 14 years of nuclear test fallout which began about 21 years ago, although 73 percent of the total ^{137}Cs deposit occurred since 1961 in the ten degree latitude band which includes Rocky Flats[28]. This surplus sediment inventory is believed to be the result of soil erosion within the watershed and subsequent sediment deposition of ^{137}Cs and other sediment associating radionuclides which had been initially deposited on surrounding soils[21]. The total activity of $^{239,240}Pu$ in the core (about 26 nCi per m^2) also represents direct deposition plus eroded soil-but from both nuclear test debris as well as resuspended material from the barrel storage area at the Rocky Flats Plant. Water samples collected at the same time as the cores were analyzed for both ^{137}Cs and $^{239,240}Pu$. The very low values found, 1.8 ± 0.3 and 0.28 ± 0.02 dpm per 100 kg respectively, show that most of the radioactivity associated with these two nuclides in the lake resides in the sediment.

We can calculate the amount of $^{239,240}Pu$ activity from Rocky Flats from the mass isotope ratio of ^{240}Pu to ^{239}Pu. By multiplying the percentage of total $^{239,240}Pu$ from Rocky Flats in the last column of Table 16 the total $^{239,240}Pu$ measured in the appropriate core segment, we obtain the Rocky Flats contribution given in Table 7. The global fallout contributions are simply the differences. By plotting the Rocky Flats values as shown in Figure 6 and integrating under the curve drawn through the data, we find a total of 15 nCi $^{239,240}Pu$ per m^2 in the core from Rocky Flats. Some fraction of this amount of Rocky Flats plutonium is from terrestrial run-off. From the 1970 soil isopleth pattern shown in Figure 1, Standley Lake should have received between 10 and 20 nCi $^{239,240}Pu$ per m^2 via direct deposition. The integrated amount of Rocky Flats plutonium in the sediment through 1970 is about 12 nCi per m^2, from Figure 6. This is in reasonably good agreement with the soil data, which implies that terrestrial run-off contributed a relatively small fraction of the Rocky Flats debris in the sediment at that time.

Since we measured a total of 26 nCi $^{239,240}Pu$ per m^2 in the core, the difference of 8 nCi per m^2 represents global fallout debris. As with ^{137}Cs, this value is substantially higher than the 1.7 nCi $^{239,240}Pu$ per m^2 assigned to the area from direct global fallout deposition[16], suggesting that about 6 nCi per m^2 of plutonium was delivered to the sediment by run-off from the surrounding area.

Table 7

Resolution of Pu Sources by Mass Spectrometry in Segments of Standley Lake Core

Depth increment (cm)	nCi ^{239,240}Pu per m^2		
	Total	Global Fallout	Rocky Flats
0 - 2	0 31	0 08	0 23
8 - 10	0 58	0 08	0 50
12 - 14	0 86	0 12	0 74
16 - 18	1 22	0 23	0 99
20 - 22	1 93	0 20	1 73
24 - 26	3 57	0 37	3 20
26 - 28	2 87	0 35	2.52
28 - 30	1 16	0 43	1 03
30 - 32	0 66	0 32	0 34
34 - 36	0 22	0 19	0 03
38 - 40	0 59	0 58	0 01
42 - 44	0 66	0 65	0.01

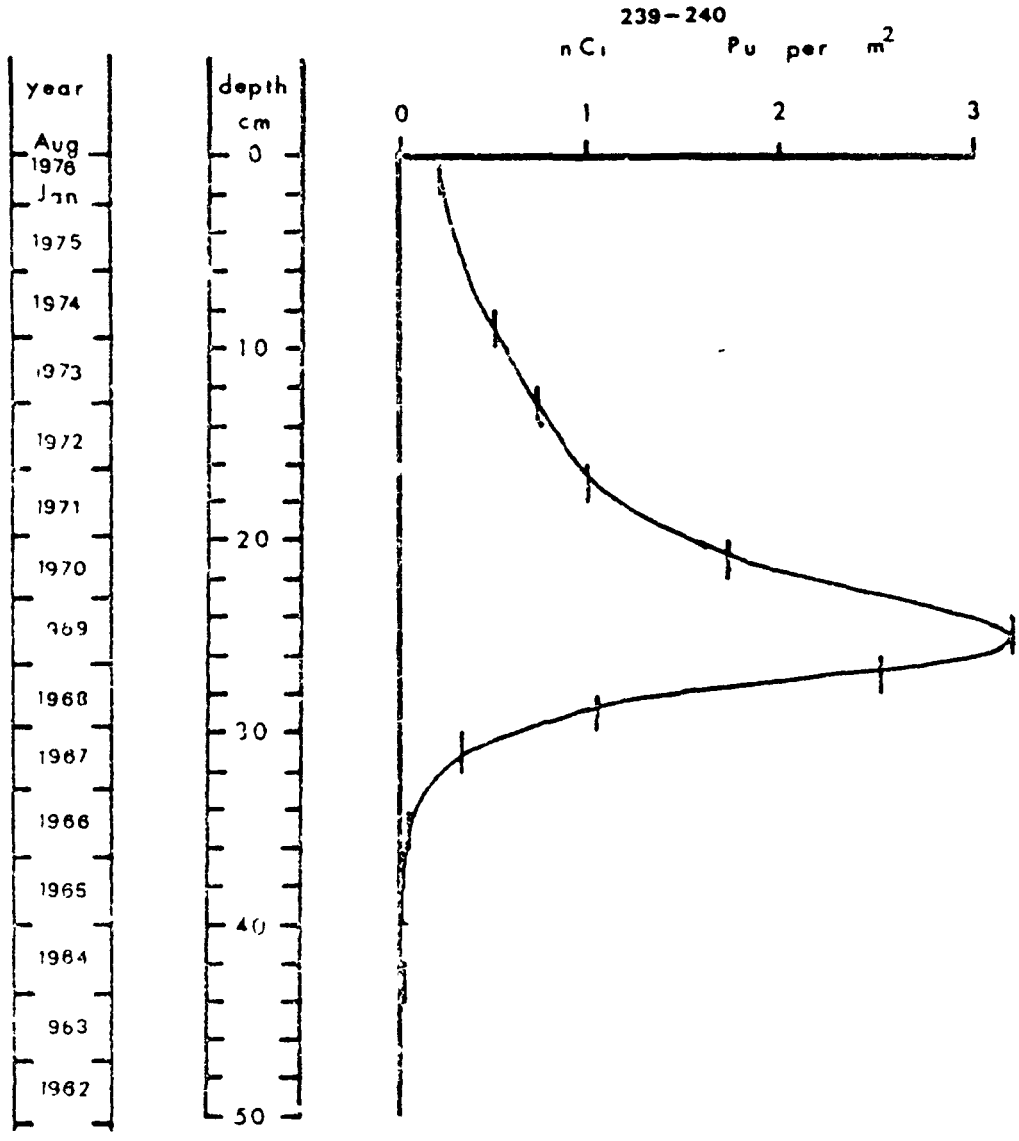


Figure 6 Depth distribution of Rocky Flats Plant plutonium in Standley Lake sediment

Conclusions

We have shown that a 50 cm sediment core taken from Standley Lake in August 1976 provides a reasonable history of global fallout cesium-137, plutonium and americium deposition as well as a transuranic deposition pattern reflecting off-site contamination from the Rocky Flats Plant. Analyses of two-centimeter segments of the core revealed nuclide maxima at the deep end which we attributed to the record in the sediment of the 1963 nuclear fallout maximum - allowing a six month delay between the fallout maximum and its deposition in the sediment. The middle section showed a high ^{238}Pu to $^{239,240}Pu$ ratio which we assumed reflected the onset of fallout from the SNAP-9A satellite. These independent time scales were practically identical justifying the construction of a core line for the sediment core which covered a 11 year period and implying a sedimentation rate of 3.4 cm per year. Following the fallout peak, another prominent peak representing only the transuranic nuclides appeared, which corresponded to contamination from the leaking barrel storage area at the Rocky Flats Plant. Isotope ratio data supported this assumption and the time of appearance, late 1969 from our sediment time line corresponded with the maximum vessel penetration of total alpha activity.

Figure 6 shows that the onset of contamination from the Rocky Flats Plant became distinguishable from global fallout activity in 1960, peaked in late 1969 and subsequently declined steadily. An evaluation of air concentrations of $^{239,240}Pu$ at several sites on the Rocky Flats property from 1971-1976 revealed a steady decrease in the annual averages[29] and downward movement of plutonium in soil, which has been demonstrated at Rocky Flats[30], would lead to reduced availabilities of plutonium to run-off. These independent but related observations support the historical trend developed from analysis of this sediment core.

From an analysis of mass isotope ratios (^{240}Pu to ^{239}Pu) we estimate that a total of 18 nCi $^{239,240}Pu$ per m^2 from Rocky Flats is in the sediment of Standley Lake. Some fraction of this amount was delivered by erosion of soil within the watershed as opposed to direct deposition of initially airborne material. The amount delivered to the sediment by the end of 1970, nevertheless, is within the range projected for Standley Lake from the plutonium aerial deposition isopleths constructed from soil samples taken in the Rocky Flats area in 1970.

Acknowledgements

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GREAT WESTERN RESERVOIR SPILLWAY SEDIMENT SAMPLING PROGRAM

PHASE I REPORT

J D Hurley

May 2, 1979

Health, Safety and Environmental Studies

ENVIRONMENTAL SCIENCES

ROCKWELL INTERNATIONAL
Rocky Flats Plant
Energy Systems Group
P O Box 464
Golden, Colorado 80401

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Great Western Reservoir
Plutonium
Spillway Sediment

GREAT WESTERN RESERVOIR SPILLWAY SEDIMENT SAMPLING PROGRAM PHASE I REPORT

J D Hurley

May 2, 1979

INTRODUCTION

Plutonium concentrations in Great Western Reservoir surface water and submerged sediments have been studied by the Environmental Protection Agency [1,2] However, no information has been recorded on transuranic concentrations in sediment which has been deposited in the Great Western Reservoir Spillway (GWRS) During periods when the reservoir is not at maximum capacity, the sediment in the spillway is not submerged Over a period of approximately 14 years, sediment has accumulated to a depth of nine feet near the stop logs (Figures 1 and 2) and to less than three feet near the southeast end of the spillway

SAMPLING PROGRAM

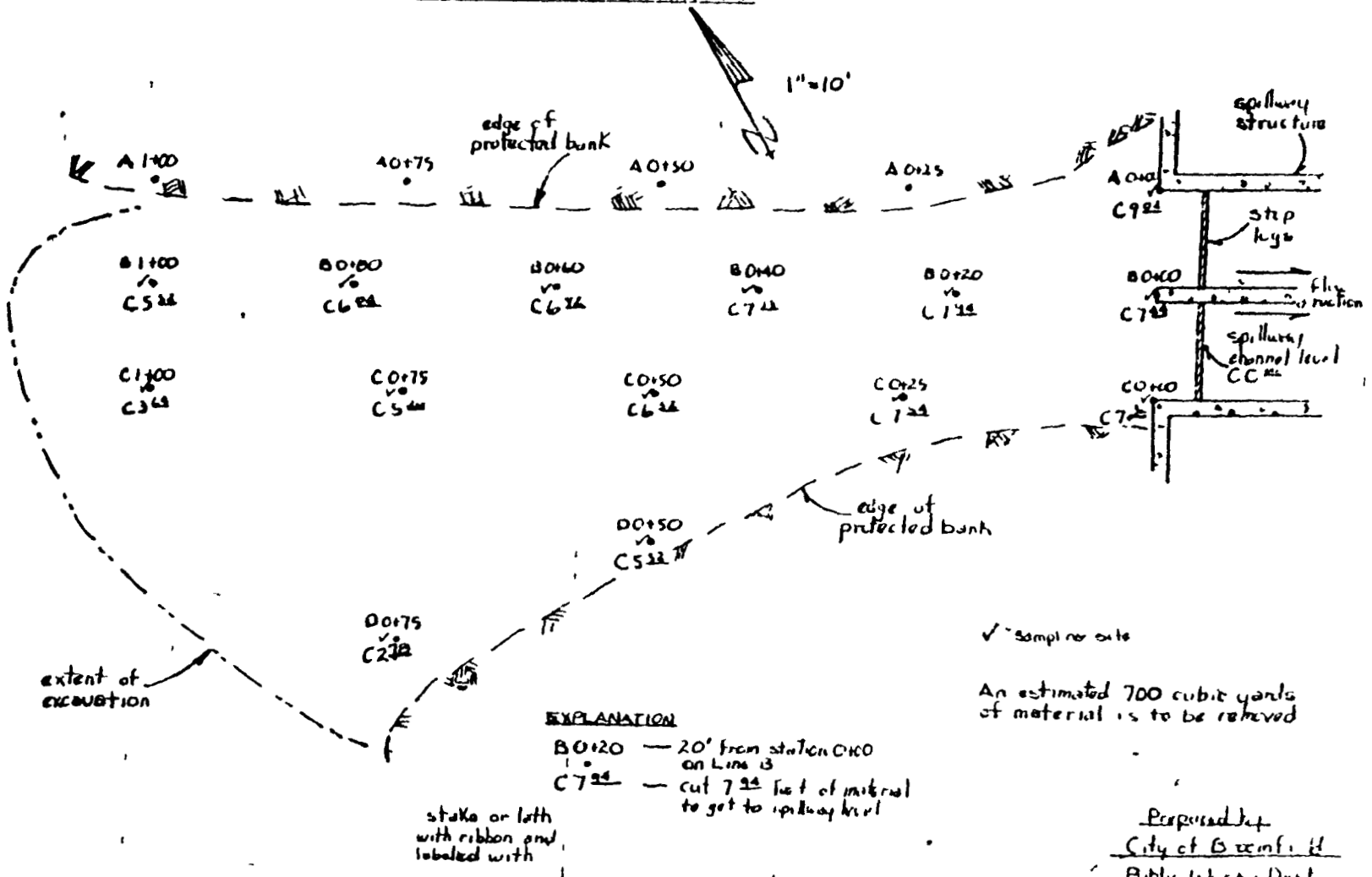
In response to a request from the Rocky Flats Area Office (RFAO), a sediment sampling program, whose purpose is to determine transuranic activity concentration in GWRS, is being performed in two phases Phase I, accomplished on March 16, 1979, consisted of taking 5-cm deep surface (general purpose) and approximately 16-cm deep shallow core samples from 14 sampling sites (Figure 2) The number of sampling sites was selected based on the activity variability observed in other comparable sediment sampling programs [1,2] The surveyed sites, indicated in Figure 2, were located uniformly over the sampling area Samples collected from the Phase I sampling effort have been analyzed for $^{239+240}Pu$ and ^{241}Am The sampling procedures and results are reported herein. Phase II is to be implemented during the removal of the spillway sediment. It will consist of obtaining a series of core samples from the wall of a trench dug in the nine foot end of the accumulated sediment

Figure 1 Spillway Sampling Area

Figure 2

GREAT WESTERN RESERVOIR

CLEANUP OF SPILLWAY ENTRANCE



Prepared by
City of Broomfield
Public Works Dept
Oct. 1976 MH

sheet 2 of 2

PHASE I SAMPLING

As mentioned, the Phase I sampling was done on March 16, 1979 The samples were taken by Health and Environmental Laboratory personnel and supervised by J D Hurley, the project leader At the time of sampling collection, the weather conditions were partly cloudy and calm with wind speeds ranging from zero to 10 miles per hour The sampling area had previously been cleared of standing vegetation The sediment samples ranged in moisture content from five to 10 percent on the surface to approximately 25 percent at a depth of approximately 21 cm Both types of samples were taken according to established procedures outlined in Reference 3 described briefly below

A General Purpose Samples

General purpose samples were taken with a 10 X 10 X 5 centimeter sampling template at the 14 locations shown in Figure 2 The five point sampling method was employed which involves taking samples at the tips and intersection of a cross, each of whose bars is one meter in length The soil from each set of five samples is then composited to give a total samples volume of 2500 cm^3 Figure 3 shows a sample being collected

B Shallow Core Samples

Shallow core samples were taken with a standard Orchard Auger (with an 8 3-cm diameter, 16-cm long barrel) at the 14 locations of Figure 2 A volume of about 750 cm^3 of soil was obtained at each location The sample collection procedure is illustrated in Figure 4

SAMPLE PRETREATMENT AND ANALYSIS

Samples are handled and analyzed according to the referenced procedures [3,4,5] These procedures include sieving, drying and ball milling of the collected material and aliquoting for gamma and alpha analysis Control samples are submitted with the collected samples to determine the quality of the results

Figure 3 Collecting a General Purpose Sample

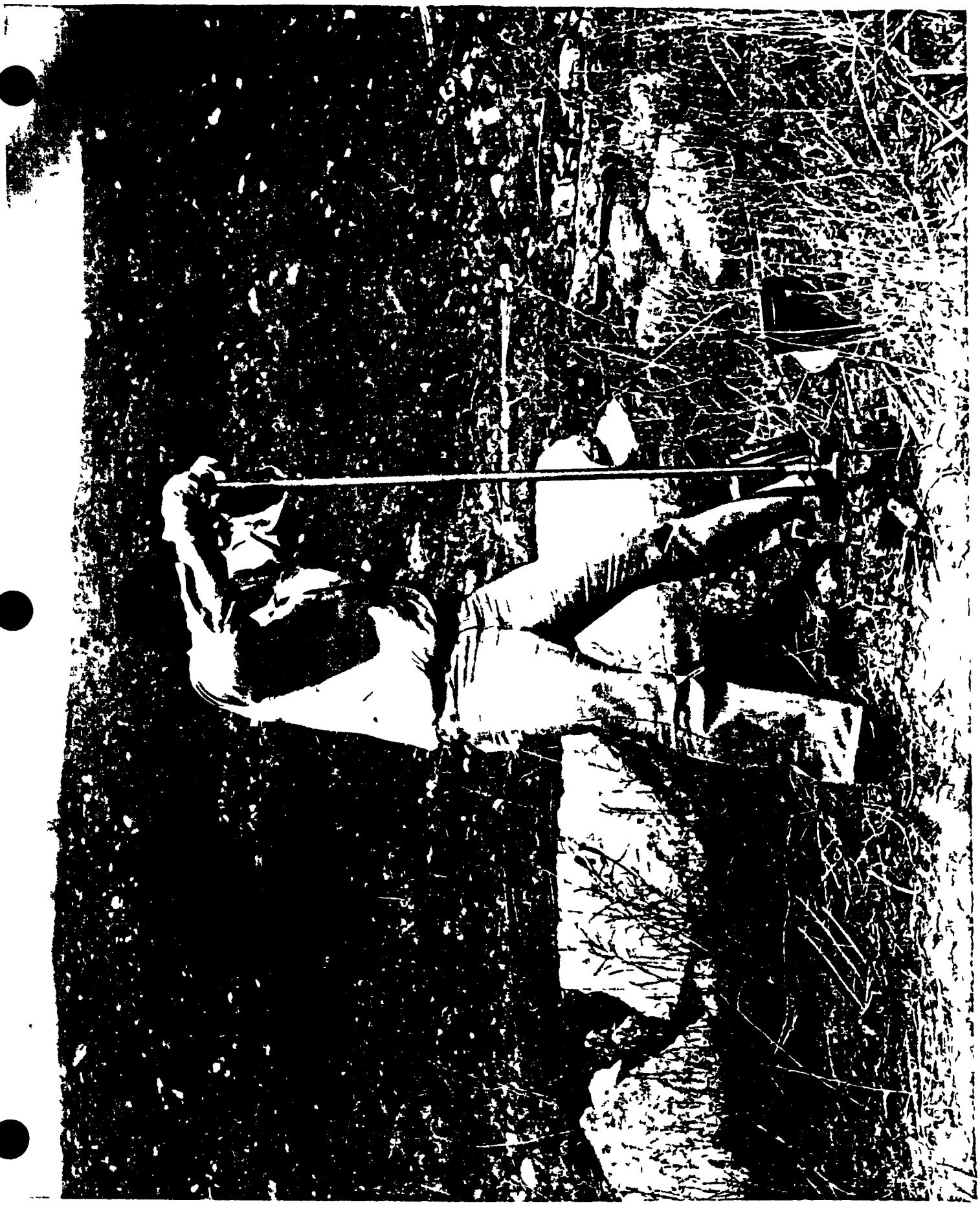


Figure 4, Collecting a Shallow Core Sample

RESULTS

Tables I, II, and III give the $^{239 + 240}Pu$ and ^{241}Am activity levels determined for the general purpose and shallow core samples The information reported in this Phase I report includes ^{241}Am data from gamma spectral analysis and ^{241}Am and $^{239 + 240}Pu$ data from chemical separation followed by alpha spectral analysis Table IV shows the quality control results associated with this series of analysis

The Tables (I, II and III) give the mean and one standard deviation values for both the general purpose and shallow core sets of measurements As the mean values for both nuclides (^{241}Am and $^{239 + 240}Pu$) for both sample types are within the combined one-standard-deviation uncertainties of each other, both sample types can be considered statistically the same

DISCUSSION

Plutonium-239, 240 and americium-241 concentrations in general purpose and shallow core samples taken at GWRS were near regional fallout background [6]. The mean ($\overline{X}$) plutonium concentration value for general purpose samples taken at GWRS was $\leq$ 074 pCi/g, standard deviation (S) 048, and $\overline{X}$ = 040 pCi/g, S = 021 for shallow core samples The $\overline{X}$ americium concentration value from alpha analysis of general purpose samples was $\leq$ 051 pCi/g, S = 031, and $\overline{X}$ = $\leq$ 030 pCi/g, S = 017 for shallow core samples Gamma analysis gave $\leq$ 036, standard deviation (S) = 008 and $\overline{X} \leq$ 031, standard deviation (S)= 004 for the general purpose and shallow core samples respectively These are lower than the alpha analysis results but not statistically different from them

Alpha analysis of all samples were performed in duplicate The values reported in Tables I and II are average values of the duplicate analysis It should be noted that the values reported in Tales I and II are not blank corrected Hence, these values are anticipated to be conservative (i e , over-estimate the actual activity present) Where $\leq$ values are reported, the number used in determining $\overline{X}$ and S is taken as the upper limit value

Table IV reports data on the quality control results It is a comparison of the prepared standard samples and the standard blank corrected values measured by the analytical laboratory The measured biases are representative of what is typically seen in measurement programs of this type[7] and indicate data of an acceptable quality

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TABLE I

GREAT WESTERN RESERVOIR SPILLWAY

ALPHA ANALYSIS

Location	$^{239+240}Pu$ (pCi/g) General Purpose	$^{239+240}Pu$ (pCi/g) Shallow Core
A0 + 00	044 ± 079	064 ± 024
B0 + 00	077 ± 012	063 ± 019
B0 + 20	076 ± 016	027 ± 016
B0 + 40	061 ± 010	015 ± 011
B0 + 60	111 ± 016	046 ± 021
B0 + 80	192 ± 019	051 ± 022
B1 + 00	124 ± 019	031 ± 016
C0 + 00	067 ± 011	083 ± 031
C0 + 25	065 ± 009	020 ± 013
C0 + 50	125 ± 015	013 ± 007
C0 + 75	026 ± 007	015 ± 012
C1 + 00	007 ± 006*	029 ± 017
D0 + 50	039 ± 018	049 ± 076*
D0 + 75	024 ± 015	051 ± 019
$\bar{\chi}$ **	≤0 074	≤0 040
S	0 048	0 021

* Average of an MDC and a positive result

** Average values are obtained by assuming less than numbers are set equal to their upper limit

TABLE 11

[illegible] RESERVOIR SPILLWAY
[illegible] SEDIMENT
ALPHA ANALYSIS (pCi/g)

Location	General Purpose	Shallow Core
A0 + 00	127 ± 120	078 ± 050
B0 + 00	062 ± 052	≤ 044 ± 044*
B0 + 20	062 ± 054	≤ 056 ± 073*
B0 + 40	063 ± 066	≤ 041 ± 045*
B0 + 60	036 ± 036	≤ 030
B0 + 80	063 ± 050	≤ 039
B1 + 00	066 ± 062	≤ 031
C0 + 00	040 ± 042	≤ 049 ± 049*
C0 + 25	052 ± 055	≤ 046 ± 053*
C0 + 50	081 ± 075	≤ 022
C0 + 75	≤ 009	≤ 060 ± 061*
C1 + 00	≤ 008	≤ 024
D0 + 50	024 ± 029	041 ± 033
D0 + 75	024 ± 024	077 ± 077
$\bar{x}$ **	≤0 051	≤0 046
S	0 031	0 017

* Average of an MDC and a positive result

** Average values are obtained by assuming less than numbers are set equal to their upper limit

TABLE III

GREAT WESTERN RESERVOIR SPILLWAY
^{241}Am IN SEDIMENT
GAMMA ANALYSIS (pCi/g)

Location	General Purpose	Shallow Core
A0 + 00	05 ± 04	≤ 03
B0 + 00	≤ 03	≤ 03
B0 + 20	≤ 03	≤ 03
B0 + 40	≤ 03	≤ 03
B0 + 60	04 ± 03	≤ 03
B0 + 80	05 ± 04	≤ 03
B1 + 00	≤ 03	≤ 03
C0 + 00	≤ 03	≤ 04
C0 + 25	≤ 03	≤ 03
C0 + 50	04 ± 03	≤ 03
C0 + 75	≤ 03	≤ 03
C1 + 00	≤ 03	≤ 03
D0 + 50	04 ± 03	≤ 03
D0 + 75	04 ± 03	04 ± 03
$\bar{X}$ *	≤0 036	≤0 031
S	0 008	0 004

* Average values are obtained by assuming less than numbers are set equal to their upper limit

TABLE IV

QUALITY CONTROL RESULTS
(pCi/g)

Analysis Type	Control Value	Measured Value	Average Bias(%)
Alpha Analysis for $^{239,240}Pu$	25	147 ± 019	-41 2
	24	169 ± 046	-29 6
	5 92	3 241 ± 41	-45 2
	5 89	5 141 ± 50	-12 7
Alpha Analysis for ^{241}Am	149	147 ± 079	- 1 3
	151	153 ± 079	+ 1 3
	1 82	1 776 ± 71	- 2 4
	1 81	2 246 ± 80	+24 1
Gamma Analysis for ^{241}Am	40 9	38 6 ± 5 8	- 5 6
		38.6 ± 5.4	

DOCUMENT D-8

"Great Western Reservoir Spillway Sediment Sampling Program Phase II Report"
(1980)

by

Rockwell International

200 10

GREAT WESTERN RESERVOIR SPILLWAY SEDIMENT SAMPLING PROGRAM PHASE II REPORT

ES-376-80-215

J D Hurley

August 6, 1980

ENVIRONMENTAL SCIENCES
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Rocky Flats Plant
Energy Systems Group
P O Box 464
Golden, Colorado 80401

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Plutonium
Spillway Sediment

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DOE, EMCBC
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Confirmed Unclassified, Not UCNI/Not OUO

GREAT WESTERN RESERVOIR
SPILLWAY SEDIMENT SAMPLING PROGRAM
PHASE II REPORT

J D Hurley

INTRODUCTION

Sampling of the sediment accumulated in the Great Western Reservoir Spillway was a project divided into two phases. Phase I sampling, completed March 16, 1979, consisted of taking 14, 5 dm deep surface samples and 14, 23 cm deep shallow core samples The results of the first phase sampling effort are reported in the Great Western Reservoir Spillway Sediment Sampling Phase I Report, May 2, 1979[1]

This report summarizes the materials, methods and analytical procedures used, as well as the data obtained, from the second and final phase sampling of the Great Western Reservoir Spillway

PHASE II SAMPLING PROGRAM

In compliance with the Rocky Flats Area Office (RFAO) request to sample sediment accumulated at Great Western Reservoir Spillway (GWRS), the second phase sampling effort was completed March 11, 1980 The second phase of the program involved obtaining seven samples from the vertical surface of a three meter high wall of sediment. The sampling site, A0 + 00 C-9, was selected on the basis of a survey by the Broomfield City Engineer estimating the greatest accumulation of sediment within the spillway (Figure 1). One sample was taken per 30 cm depth of accumulated sediment Each of the seven samples extended approximately 16 cm into the wall of sediment Samples collected during the Phase II sampling were analyzed for plutonium-239 + 240 and americium-241.

PHASE II SAMPLING

The seven samples obtained March 11, 1980 were collected by Health and Environmental Laboratory personnel under the supervision of J. D. Hurley,

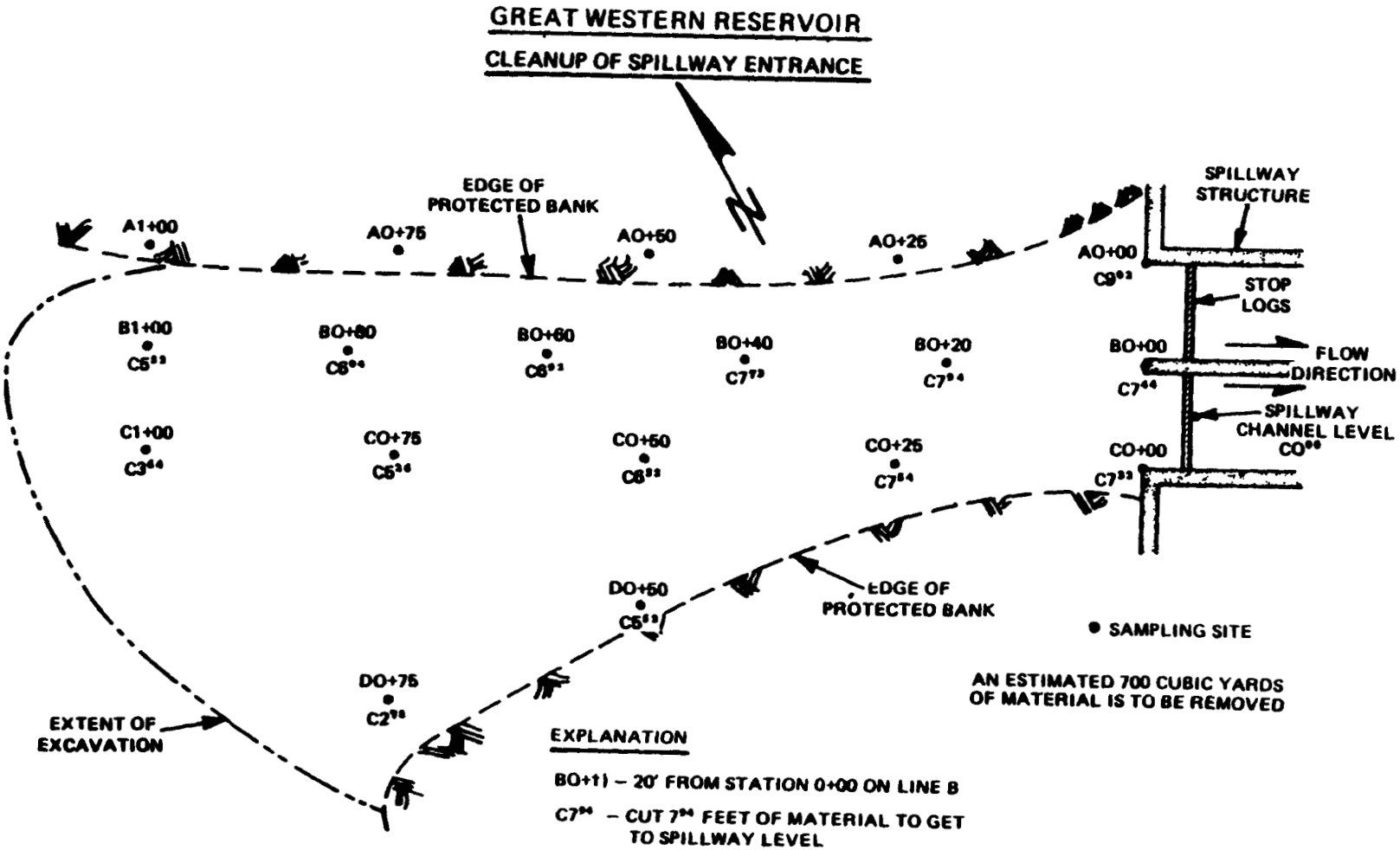

GREAT WESTERN RESERVOIR
CLEANUP OF SPILLWAY ENTRANCE
N
EDGE OF PROTECTED BANK
SPILLWAY STRUCTURE
A1+00
AO+75
AO+50
AO+25
AO+00
C9^93
STOP LOGS
B1+00
C5^53
BO+80
C8^94
BO+60
C8^92
BO+40
C7^73
BO+20
C7^94
BO+00
C7^44
FLOW DIRECTION
SPILLWAY CHANNEL LEVEL
CO^00
C1+00
C3^44
CO+75
C5^36
CO+50
C8^92
CO+25
C7^84
CO+00
C7^33
DO+50
C5^53
EDGE OF PROTECTED BANK
DO+75
C2^78
EXTENT OF EXCAVATION
SAMPLING SITE
AN ESTIMATED 700 CUBIC YARDS OF MATERIAL IS TO BE REMOVED
EXPLANATION
BO+11 – 20' FROM STATION 0+00 ON LINE B
C7^94 – CUT 7^94 FEET OF MATERIAL TO GET TO SPILLWAY LEVEL

Figure 1

the project leader At the time of sample collection the weather conditions were overcast and calm with wind speeds ranging from 0-10 mph. The temperature ranged from 45°F at 9 00 a m. to 55°F by late afternoon All samples were taken from a sediment wall located at the eastern end of the GWR spillway supported by nine 15 cm X 30 cm X 3 5 m wooden stoplogs A 30 cm^2 section was cut from each log, providing easy access to the desired sampling area and continued support for the 3M sediment wall (Figure 2)

A standard Orchard Auger* (with an 8 3 cm diameter, 16 cm long barrel) was used to obtain the seven samples. A volume of about 750 cm^3 of soil was obtained for each sample The sample collection procedure is illustrated in Figure 3 All samples were taken according to established Rocky Flats sampling procedures

SAMPLE PRETREATMENT AND ANALYSIS

Samples were handled and analyzed according to Rocky Flats laboratory procedures The procedures include drying, ballmilling, sieving and aliquoting of the collected material prior to alpha and gamma analysis Control samples prepared at the two sigma level were also submitted for alpha analysis to determine the quality of the results

RESULTS

Tables I, II and III give the plutonium-239 + 240 and americium-241 activity levels determined for the samples obtained during the second phase sampling effort The information reported in Tables I and II respectively include plutonium-239 + 240 and americium-241 data from chemical separation followed by alpha spectral analysis. Table III shows americium-241 activity levels obtained by gamma spectral analysis

Alpha analysis of all samples were performed in duplicate and were blank corrected The values reported in Tables I and II are average values of the duplicate analyses.

* Standard Type #R-HEO, ARTS Machine Shop, American Falls, Idaho

Figure 2 Eastern End of Great Western Reservoir Spillway

Figure 3 A Demonstration of the Sample Collection Procedure at Great Western Reservoir

DISCUSSION

Concentrations of plutonium-239 + 240 in sediment samples taken at GWRS during the second phase sampling effort were well below the 2 d/m/g (approximately 0 9 pCi/g) activity screening level adopted by the Colorado State Board of Health[2]. The mean plutonium concentration value ($\bar{x}$) for plutonium-239 + 240 was 040 pCi/g, with a standard deviation (s) of 026

Analysis of americium-241 activity in sediment was performed by alpha and gamma spectral analysis. When comparing the alpha and gamma americium-241 activity all less than values were taken as their upper limit A sign test applied to these values showed no difference in the two data sets

Even though the expected plutonium-239 + 240 to americium-241 ratio is of the order of ten[3], the observed average ratio (by alpha analysis) was calculated as being less than 1 This is probably a reflection of the nearness to the detection limits of the americium values obtained by alpha spectroscopy

Inspection of the plutonium and americium results associated with sediment depth indicates sediment activity in GWRS essentially showed little variation with depth This finding was not surprising since it was thought that the sediment sampled in the spillway was deposited as a result of hillside erosion, deposition by wave action and mixing

REFERENCES

1 Hurley, J. D., Great Western Reservoir Spillway Sediment Sampling Program, Phase I Report, May 2, 1979.

2 State of Colorado Rules and Regulations Pertaining to Radiation Control, RH 4.21 Permissible Levels of Radioactive Material in Uncontrolled Areas Adopted by Colorado State Board of Health, March 21, 1973

3 Final Environmental Impact Statement (Final Statement to ERDA 1545-D) Rocky Flats Plant Site, Golden, Jefferson County, Colorado. U S Department of Energy, April 1980. Volume 1 of 3, pp 2-92, 2-170 and 3-30

TABLE I Great Western Reservoir Spillway
Phase II Sampling Plutonium-239 + 240 in Sediment

Alpha Analysis

Location*	239 + 240 Pu (pCi/g)
A0 + 00 C9-1	055 ± 011
A0 + 00 C9-2	070 ± 017
A0 + 00 C9-3	068 ± 013
A0 + 00 C9-4	048 ± 011
A0 + 00 C9-5	018 ± 006
A0 + 00 C9-6	016 ± 007
A0 + 00 C9-7	006 ± 005
$\bar{x}$	040
s	026

*See text, page 1, for sample location explanation

TABLE II Great Western Reservoir Spillway
Phase II Sampling Americium-241 in Sediment

Alpha Analysis

Location	241-Am (pCi/g)
A0 + 00 C9-1	055 ± 040
A0 + 00 C9-2	063 ± 043
A0 + 00 C9-3	055 ± 041
A0 ± 00 C9-4	038 ± 038
A0 ± 00 C9-5	058 ± 041
A0 ± 00 C9-6	117 ± 048
A0 ± 00 C9-7	063 ± 035
$\bar{x}$	064
s	025

*See text, page 1, for sample location explanation

TABLE III Great Western Reservoir Spillway
Phase II Sampling Americium-241 in Sediment

Gamma Analysis

Location*	241-Am (pCi/g)**
A0 + 00 C9-1	< 067
A0 + 00 C9-2	< 092
A0 + 00 C9-3	< 069
A0 + 00 C9-4	< 098
A0 + 00 C9-5	< 087
A0 + 00 C9-6	< 077
A0 + 00 C9-7	< 015

* See text, page 1, for sample location explanation
** 241-Am results were all below MDA The results of each sample was set equal to MDA thus accounting for the absence of uncertainty values

200.12

CORRES. CONTROL
OUTGOING LTR. NO
85-RF-0457

DIST	LTR	ENCL
ORR J.E.		
BENJAMIN, A.		
ADAMS, M.L.		
CROSSLAND W.D.		
LANGHEIM, G.R.		
McNETT J.F.		
OWEN F.G.		
REBRO W.L.		
SHANNON, W.M.		
SMITH R.E.		
VEJVODA, E.		
WEIDNER, C.W.		
WESTON W.F.		
WIEDERECHT D.A.		
WILSON G.L.		
WOZNIAK B.D.		
YODER R.E.		
YOUNG E.R.		
BAKER J.W.		
BURNETT, E.L.		
BYRNE, J.P.		
CAMPBELL, G.W.	X	X
CARNIVAL, G.J.		
CHANDA, R.N.		
ELLIS, H.R.		
GILBERT K.V.		
HARMAN L.K.		
HEALY T.J.		
HURLEY J.D.		
JOHNSON, C.H.		
[redacted]EG D.M.		
[redacted]UDENBURG, G.E.		
NAIMON E.R.		
NICHOL, W.R.		
ROBERTS, J.K.		
SMITH M.J.		
VELASQUEZ, R.N.		
WICKLAND C.E.		
CORRES CONTROL	X	X
Hornbacher, D.B.	X	X
[redacted]	X	X
Kaspercpuk, C.R.	X	X
Setlock, G.H.	X	X

CLASSIFICATION	LTR	ENCL
UNCLASSIFIED		
CONFIDENTIAL		
SECRET		

AUTH. CLASSIFIER SIG.
C.L. Kaspercpuk
DATE 2-15-85

IN REPLY TO LTR. NO

[redacted] APPROVALS

ORIG. & TYPIST INITIALS
GHS/dlb

Rocky Flats Plant
North American Space Operations
Rockwell International Corporation
P.O. Box 464
Golden, Colorado 80402-0464
(303) 497-7000
Contractor to U.S. Department of Energy

Rockwell International

February 14, 1985 85-RF-0457

James R. Nicks
Area Manager
DOE, RFAO

GREAT WESTERN RESERVOIR SEDIMENT CORES

In the summer of 1983 Rockwell conducted a geochemical sampling project on Great Western Reservoir. As part of that study a series of surficial grab and sediment core samples were collected and either shared or split with the City of Broomfield and the Colorado Department of Health. Results of plutonium in forty-eight surficial sediment samples were made public in a joint presentation with the City of Broomfield last May. The informal agreement made with Broomfield called for reporting of plutonium in the core samples 9 - 12 months after that presentation. Release of these data has tentatively been set for another joint Rockwell/Broomfield presentation to be made at the March 26, 1985, State Exchange Meeting in Broomfield. In preparation for this disclosure, I am providing copies of both the Rockwell and City of Broomfield* datasets for you and your staff to review.

Attached you will find the following:

- Sample location map for Great Western Reservoir. (Rockwell)
- Tabulated Pu-239,240 data for four sediment cores spread geometrically across the reservoir. (Rockwell)
- Graphs (Pu-239,240 concentration versus depth in the sedimentary column for these same four sediment cores. (Rockwell)
- Plot of experimental values versus +/- sigma core KB4 (note all graphs were plotted with the plutonium concentration at the sediment interval midpoint; this plot illustrates that the uncertainty interval around the data values is small, to allow point plotting without error terms). (Rockwell)

*Samples analyzed by Acculabs, Inc., data obtained from K. Kochevar (City of Broomfield)

- Plot of cesium-137 concentration versus depth in the sedimentary column (used to age date core KB4 and ascertain typical sedimentation rate for the deeper area of the reservoir (eastern area - 0.82 " per year)). (Rockwell)
- Tabulated Pu-239,240 data for three sediment cores (duplicate core samples collected at same locations). (Broomfield)
- Graphs (Pu-239,240 concentration versus depth in the sedimentary column) for these same three sediment cores. (Broomfield)

The plutonium data from both Rockwell and Broomfield is as expected with no anomalies. Geochemically, one would expect to see concentrations near previously reported maximums at depth and values approaching background in the surface intervals. Due to relatively constant sedimentation rates (approximately 1 " per year) in Great Western and changes in routine operations at Rocky Flats (i.e. zero discharge goals) over the past decade, this trend in the data was evident. Maximum values previously reported were 4.1 and 6.0 pCi/gram (EPA and Battelle 1970's, respectively). Maximum values from this study were 5.4 and 4.9 pCi/gram (core KB4; Rockwell and Broomfield data, respectively) for plutonium. Each of these maximum values occurred at depths of 17.0 and 7.5 inches, respectively. When evaluating these data please note that core KB4 is plotted on a 0-6.0 pCi/gram scale while the remainder of the cores are plotted on a 0-2.0 pCi/gram scale. Also, note that Broomfield's data represent one inch core sections while Rockwell's data represent two inch intervals. The cores selected by Broomfield were not quite as long as the Rockwell cores; two inch intervals were utilized by Rockwell to accommodate more radionuclide analyses by Rockwell.

An interesting observation was made by G. H. Setlock (EA&C) as he compiled these sediment core data. The peak concentrations of both Cesium-137 and plutonium-239,240 coincide at depth in core KB4. Peak Cesium-137 concentration is used as a time horizon in sediment cores (i.e. maximum cesium-137 level corresponds to 1962 horizon) due to the peak of atmospheric fallout from weapons testing. This technique is a routine practice by geologists and is frequently employed since lake sediments represent the best natural record of the environmental history of an area. The coexistence of both radionuclides's maxima and other information (i.e. lead-210 data), strongly implies that significant quantities of plutonium in the deeper sediments of Great

Western Reservoir may have been deposited there as a result of atmospheric fallout and do not entirely derive from Rocky Flats. This preliminary hypothesis will be independently pursued through additional cesium-137 analyses on other Great Western and Standley Lake cores as well as plutonium isotopic studies to "fingerprint" the source of the plutonium. This idea along with other statistical studies of the Great Western Reservoir data (i.e. plutonium inventory in Great Western sediments) which were previously brought to your attention will be initiated in FY85. When these studies are completed, RFAO will receive a detailed briefing.

Please review the attached Great Western Reservoir data. If your or your staff have any questions or problems with reporting these plutonium data at the March 26, 1985, State Exchange Meeting, please contact me.

George W. Campbell, Acting Director
Health, Safety and Environment
Rocky Flats Plant
North American Space Operations

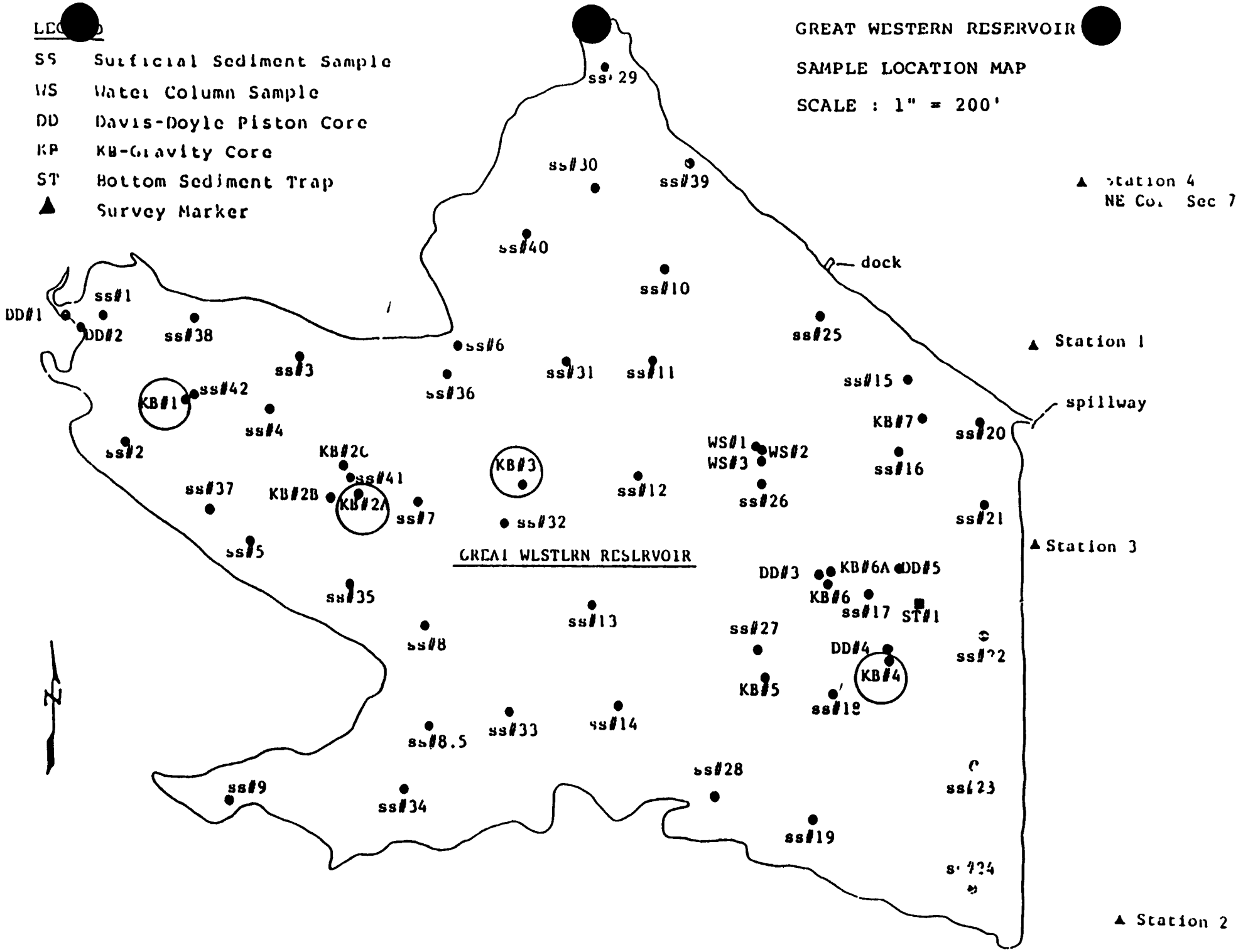
Orig. and 1 cc - J. R. Nicks

Enc.

GREAT WESTERN RESERVOIR
SEDIMENT CORE DATA / GRAPHS

ROCKWELL INTERNATIONAL

2/85


LEGEND
SS Surficial Sediment Sample
WS Water Column Sample
DD Davis-Doyle Piston Core
KB KB-Gravity Core
ST Bottom Sediment Trap
Survey Marker
GREAT WESTERN RESERVOIR
SAMPLE LOCATION MAP
SCALE : 1" = 200'
Station 4
NE Cor Sec 7
dock
spillway
Station 1
Station 3
Station 2
GREAT WESTERN RESERVOIR
ss#29
ss#30
ss#39
ss#40
ss#10
ss#25
ss#1
DD#1
DD#2
ss#38
ss#6
ss#3
ss#31
ss#11
ss#15
KB#1
ss#42
ss#36
ss#4
KB#7
ss#20
ss#2
KB#2C
KB#3
WS#1
WS#2
WS#3
ss#16
ss#41
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KB#2B
KB#2A
ss#12
ss#26
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ss#32
ss#21
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KB#6
ss#17
ST#1
ss#35
ss#13
ss#27
ss#8
DD#4
ss#22
KB#4
KB#5
ss#18
ss#8.5
ss#33
ss#14
ss#28
ss#23
ss#9
ss#34
ss#19
ss#24

GREAT WESTERN RESERVOIR
SEDIMENT CORE RESULTS – PLUTONIUM 239,240
ROCKWELL INTERNATIONAL

DEPTH	Pu–239,240 (pCi/gram)	
(inches)	GWR–KB1	GWR–KB2
0 – 2	.20 +/– .023	.19 +/– .023
2 – 4	.23 +/– .025	.18 +/– .021
4 – 6	.75 +/– .062	.16 +/– .020
6 – 8	1.00 +/– .078	.14 +/– .019
8 – 10	1.00 +/– .082	.17 +/– .022
10 – 12	.11 +/– .017	.67 +/– .052
12 – 14		.97 +/– .067
14 – 16		1.30 +/– .088

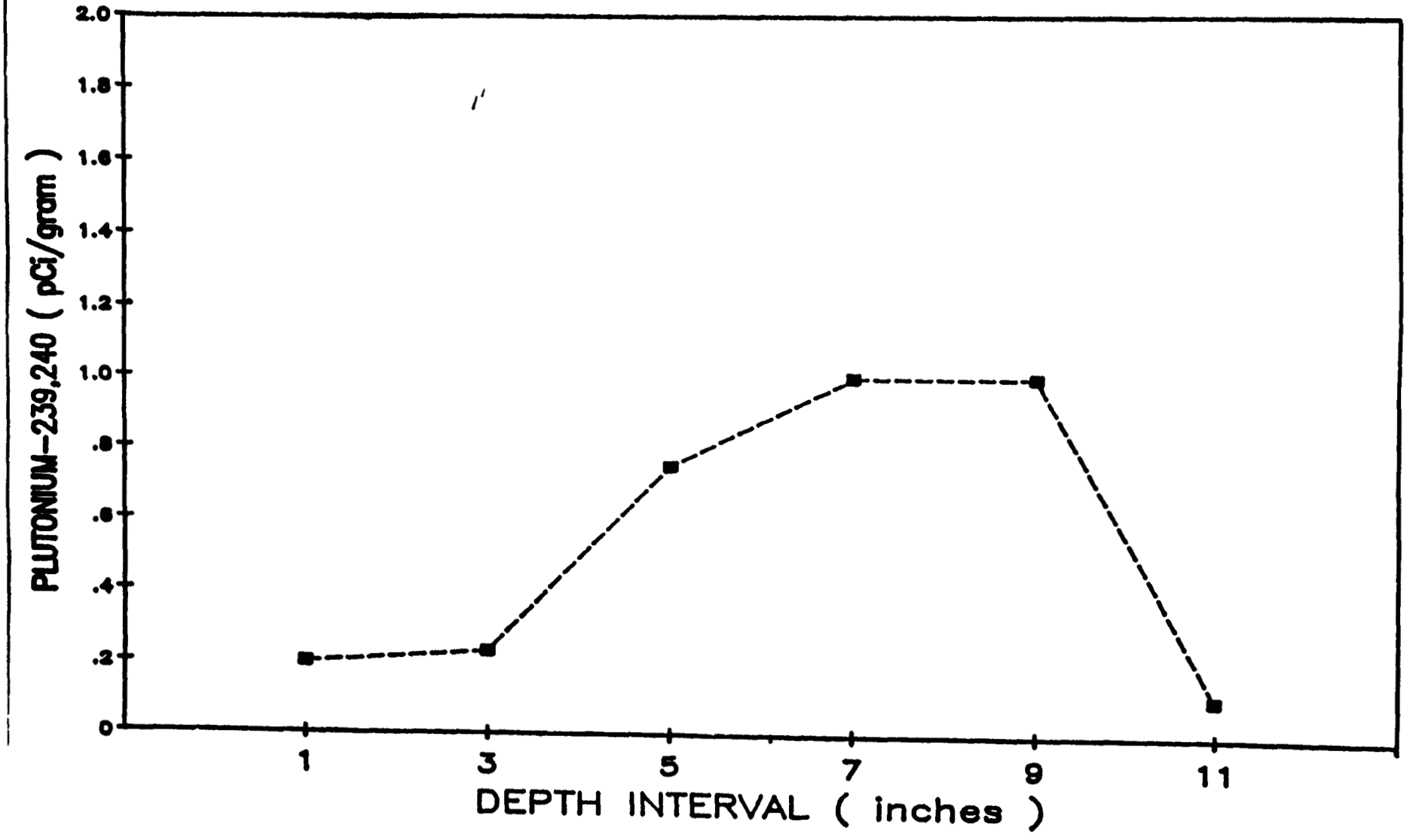
GHS 2/85

GREAT WESTERN RESERVOIR
SEDIMENT CORE RESULTS – PLUTONIUM 239,240
ROCKWELL INTERNATIONAL

DEPTH	Pu–239,240 (pCi/gram)	
(inches)	GWR–KB3	GWR–KB4
0 – 2	.16 +/– .021	.25 +/– .026
2 – 4	.18 +/– .022	.39 +/– .036
4 – 6	.14 +/– .018	.95 +/– .069
6 – 8	.24 +/– .024	1.40 +/– .099
8 – 10	1.30 +/– .088	1.60 +/– .110
10 – 12	.75 +/– .057	2.10 +/– .130
12 – 14	1.50 +/– .010	3.70 +/– .250
14 – 16	1.90 +/– .130	3.80 +/– .230
16 – 18		5.40 +/– .390
18 – 20		3.30 +/– .190

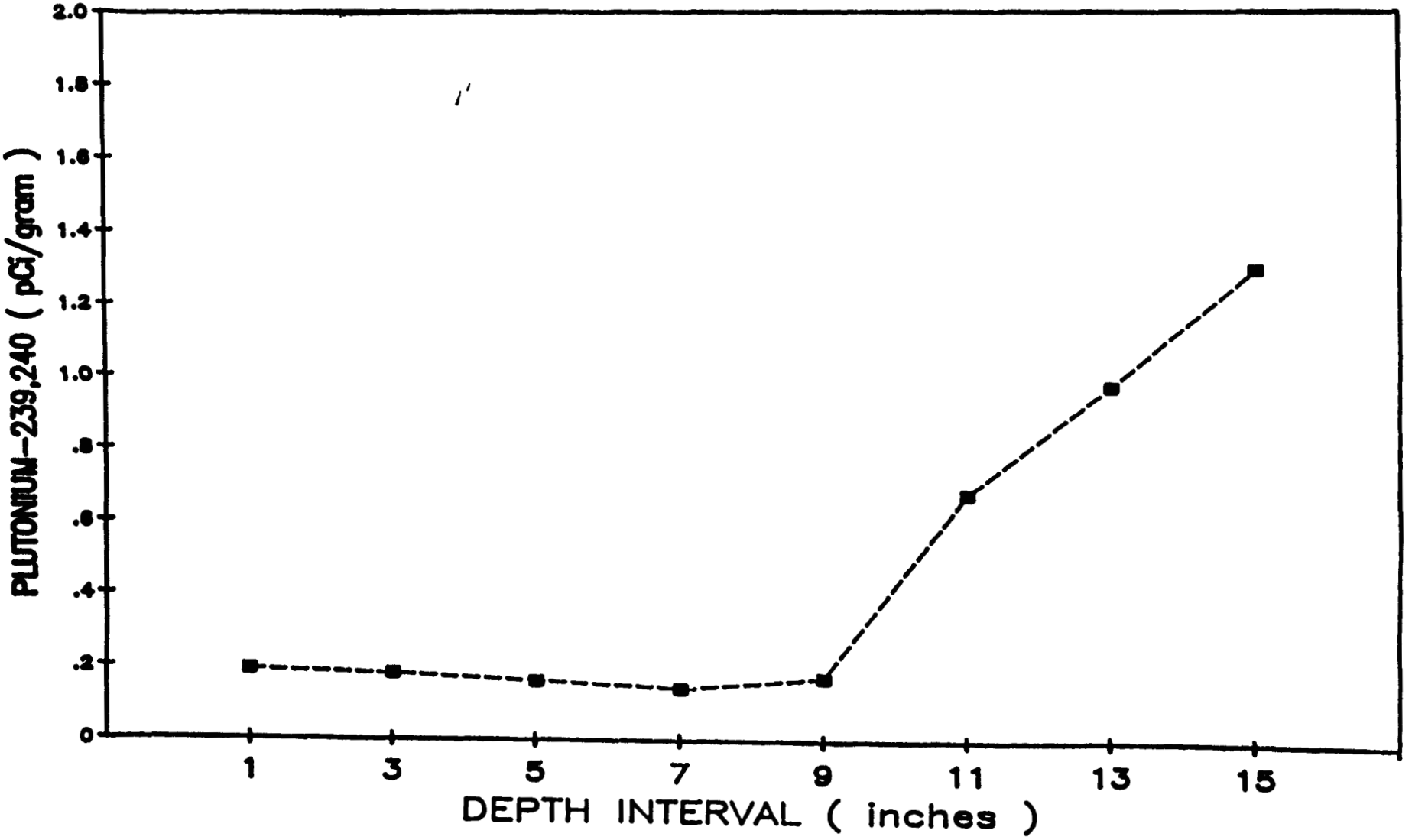
GHS 2/85

GREAT WESTERN RESERVOIR — CORE KB1
PLOT OF Pu—239,240 VS. SEDIMENT DEPTH
ROCKWELL INTERNATIONAL



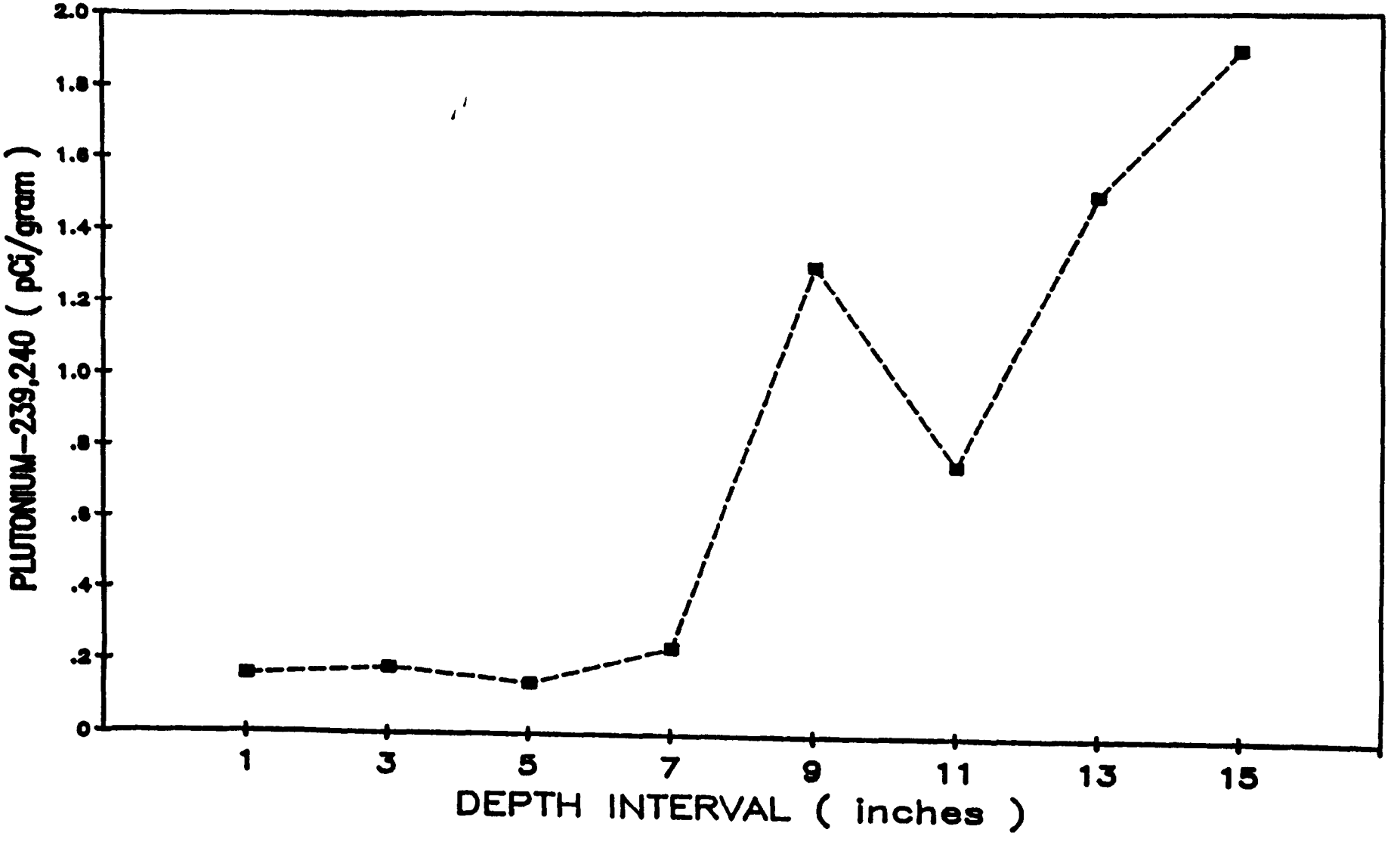
QHS 2/85

GREAT WESTERN RESERVOIR — CORE KB2
PLOT OF Pu—239,240 VS. SEDIMENT DEPTH
ROCKWELL INTERNATIONAL



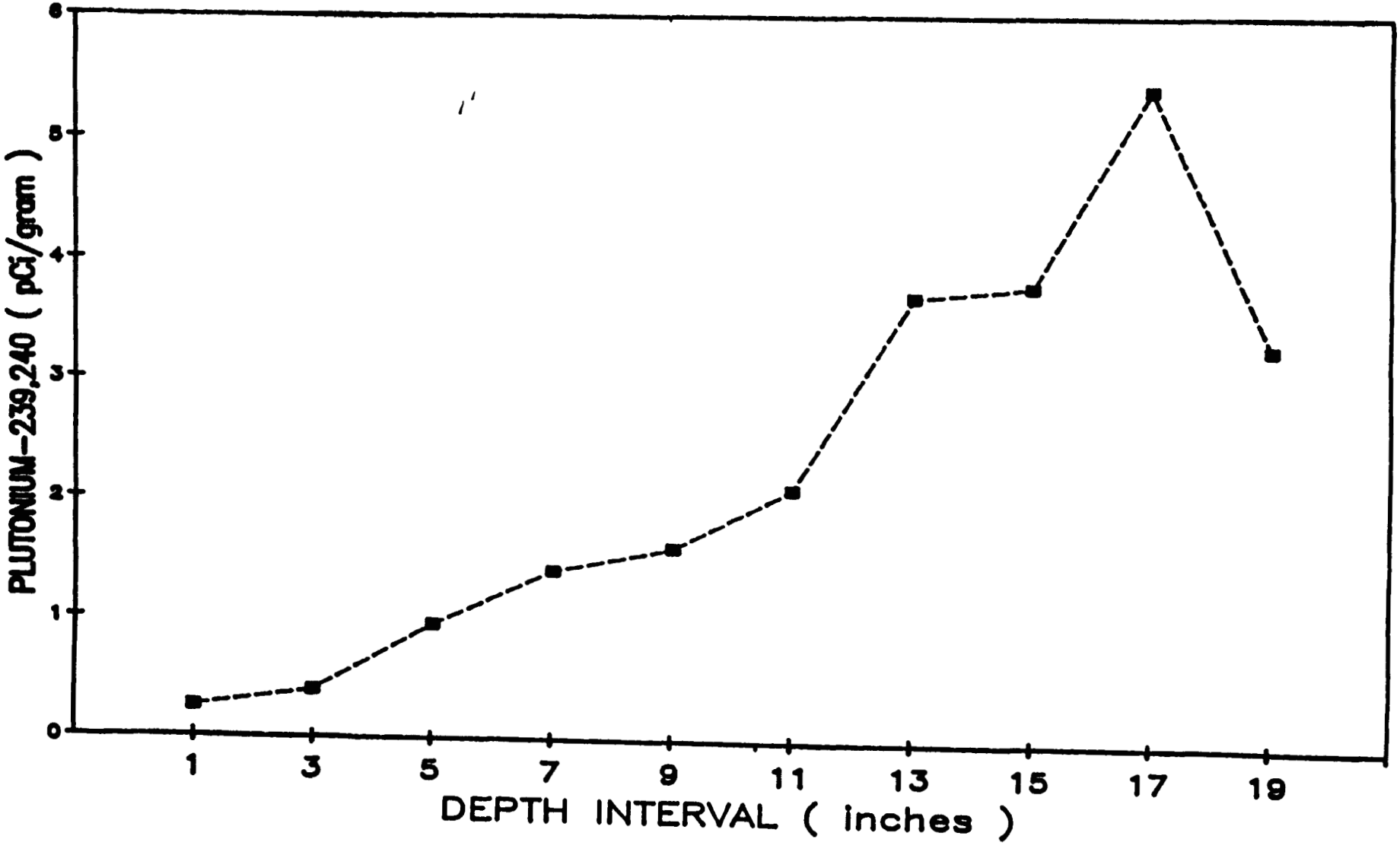
GHS 2/85

GREAT WESTERN RESERVOIR — CORE KB3
PLOT OF Pu—239,240 VS. SEDIMENT DEPTH
ROCKWELL INTERNATIONAL



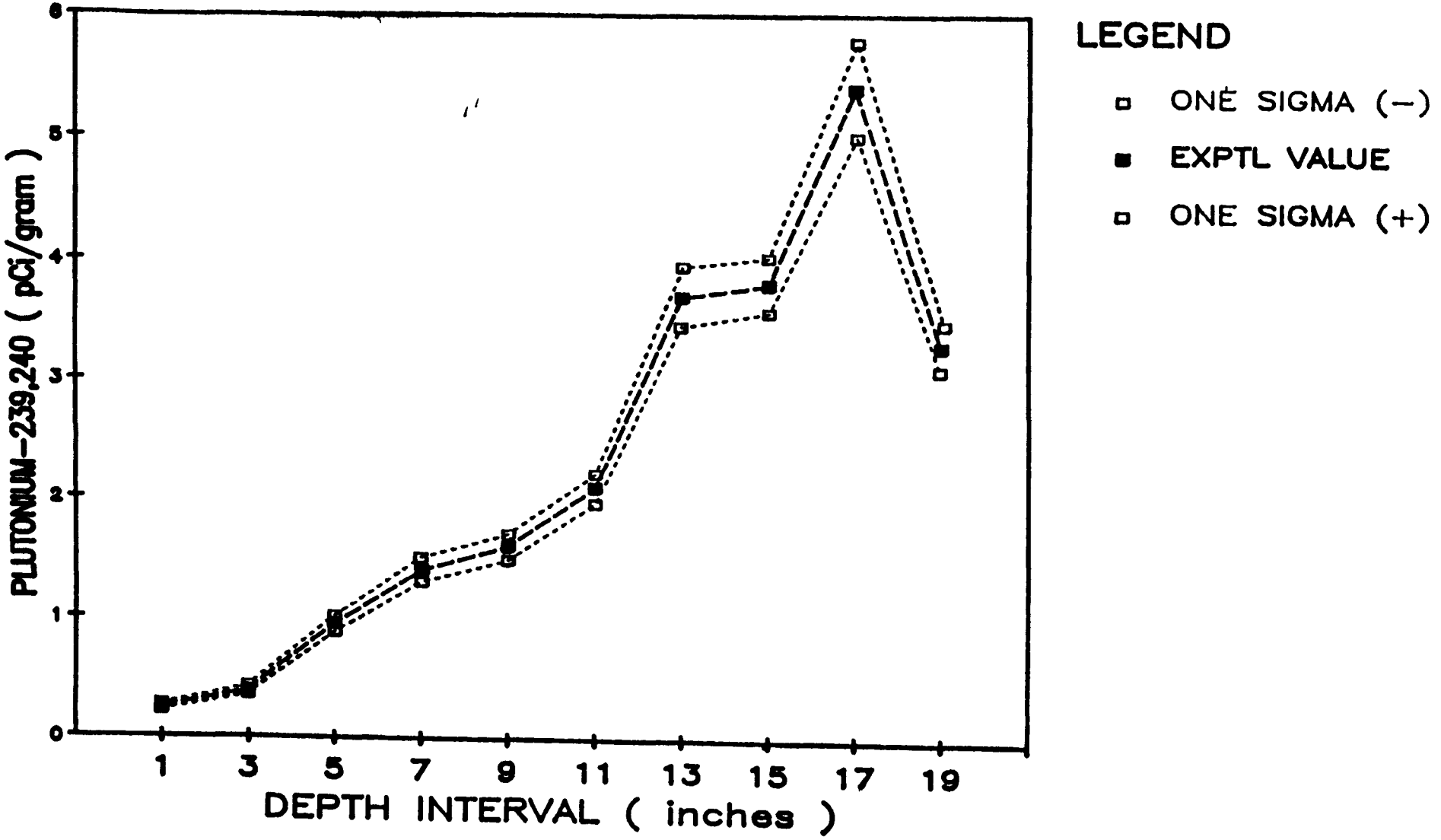
GHS 2/85

GREAT WESTERN RESERVOIR – CORE KB4
PLOT OF Pu–239,240 VS. SEDIMENT DEPTH
ROCKWELL INTERNATIONAL



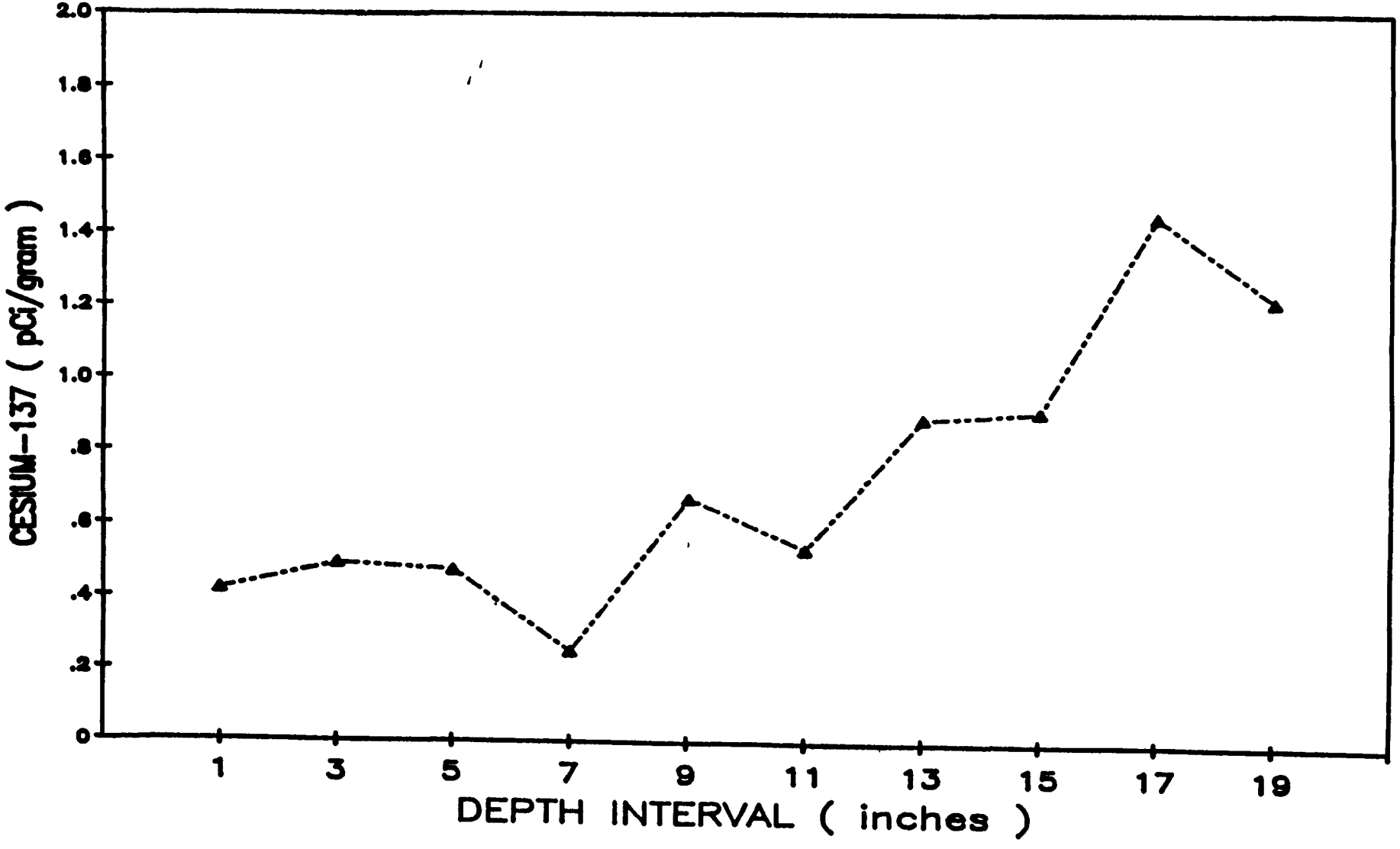
GHS 2/85

GREAT WESTERN RESERVOIR — CORE KB4
PLOT OF Pu—239,240 VS. SEDIMENT DEPTH
ROCKWELL INTERNATIONAL



GHS 2/85

GREAT WESTERN RESERVOIR — CORE KB4
PLOT OF Cs—137 VS. SEDIMENT DEPTH
ROCKWELL INTERNATIONAL



GHS 2/85

GREAT WESTERN RESERVOIR
SEDIMENT CORE DATA / GRAPHS

CITY OF BROOMFIELD

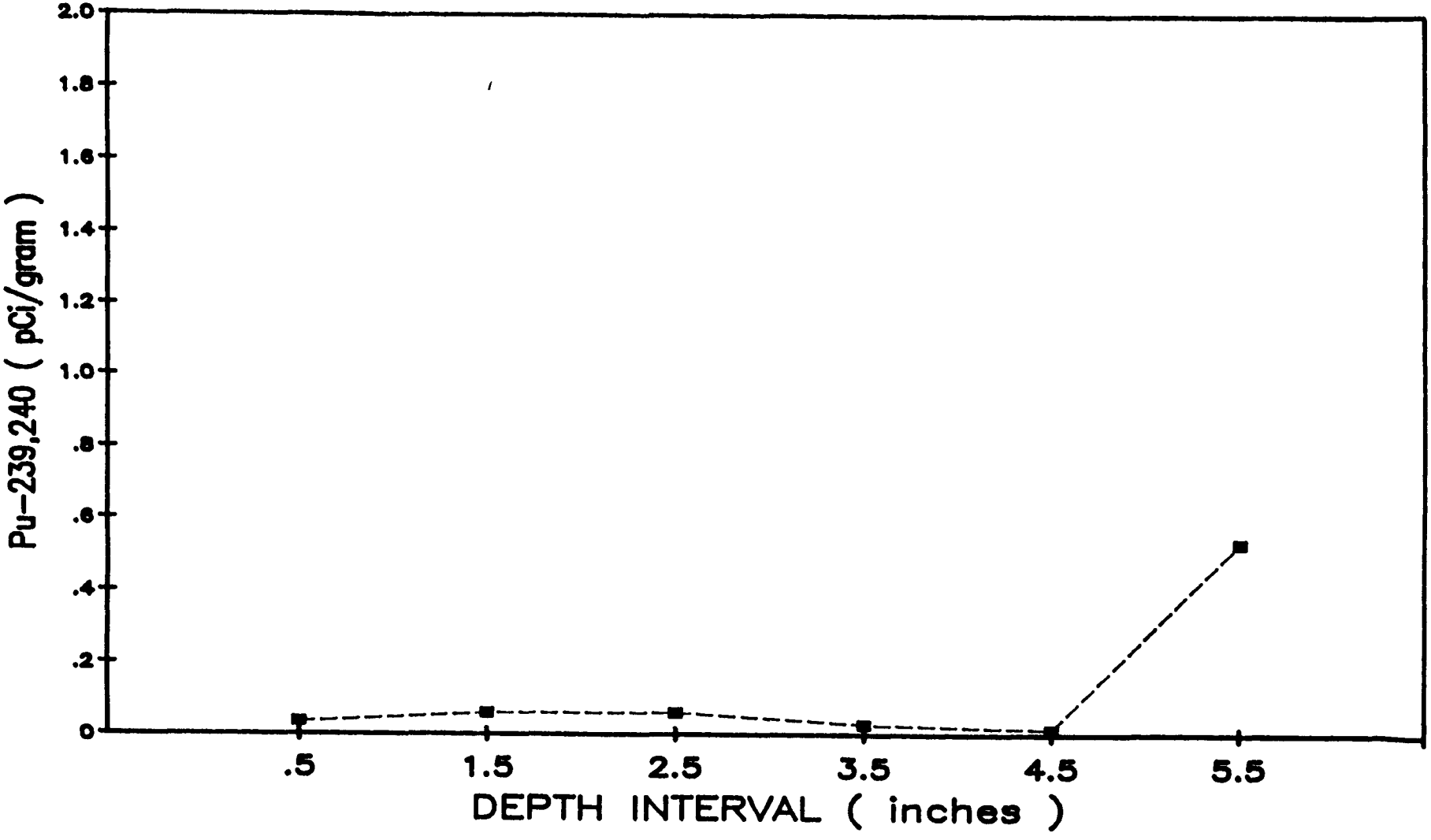
2/85

GREAT WESTERN RESERVOIR
SEDIMENT CORE RESULTS – PLUTONIUM 239,240
CITY OF BROOMFIELD

DEPTH	Pu–239,240 (pCi/gram) **		
(inches)	GWR–KB1	GWR–KB3	GWR–KB4
0 – 1	.034	.650	.360
1 – 2	.057	.720	.470
2 – 3	.059	1.200	.810
3 – 4	.025	1.500	.890
4 – 5	.013	1.300	1.600
5 – 6	.530	1.200	1.700
6 – 7			2.200
7 – 8			4.900
8 – 9			2.800
9 – 10			4.000
10 – 11			1.800

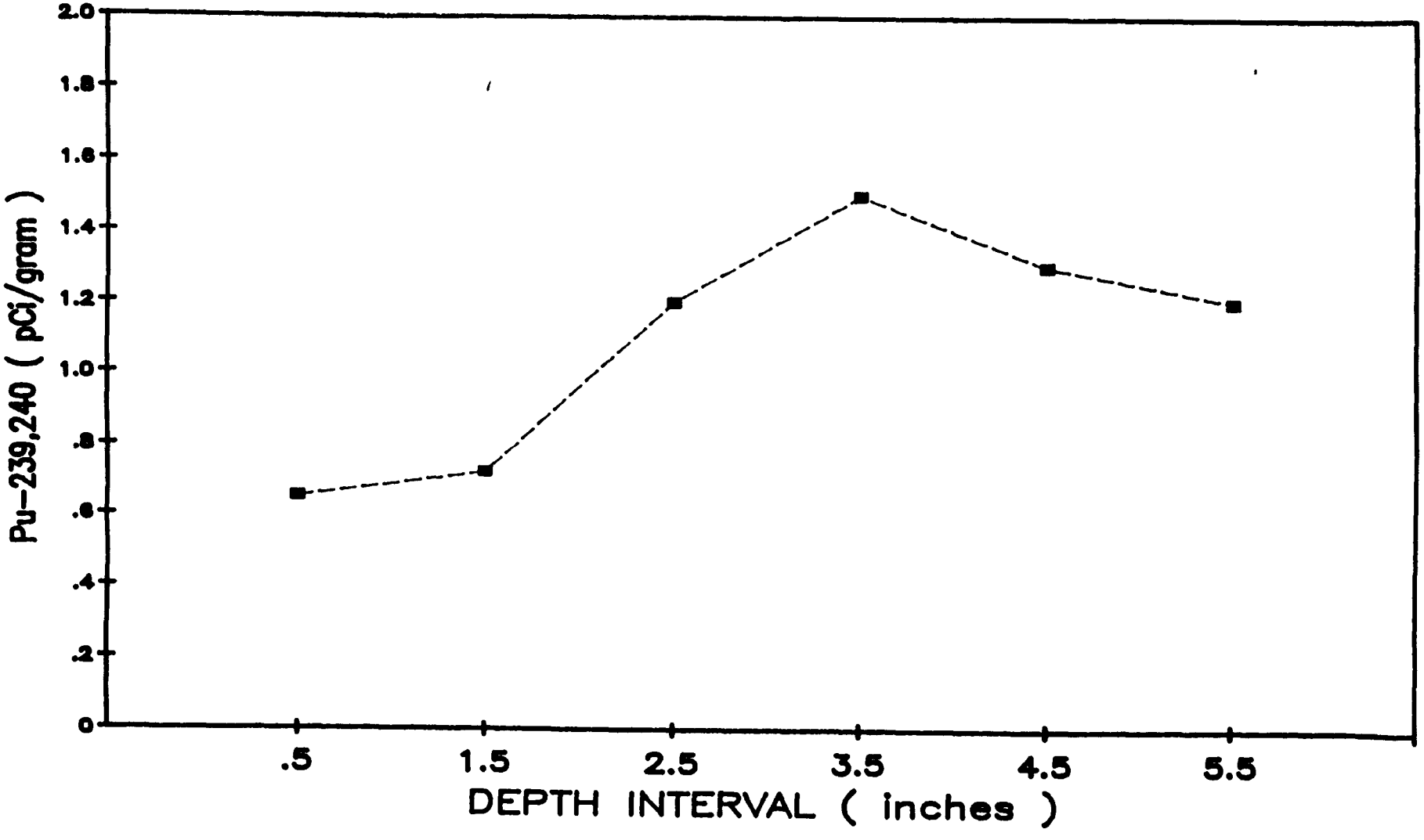
** ANALYSES BY ACCULABS, INC. / ERROR TERMS UNKNOWN GHS 2/85

GREAT WESTERN RESERVOIR – CORE KB1
PLOT OF Pu–239,240 vs. SEDIMENT DEPTH
CITY OF BROOMFIELD *



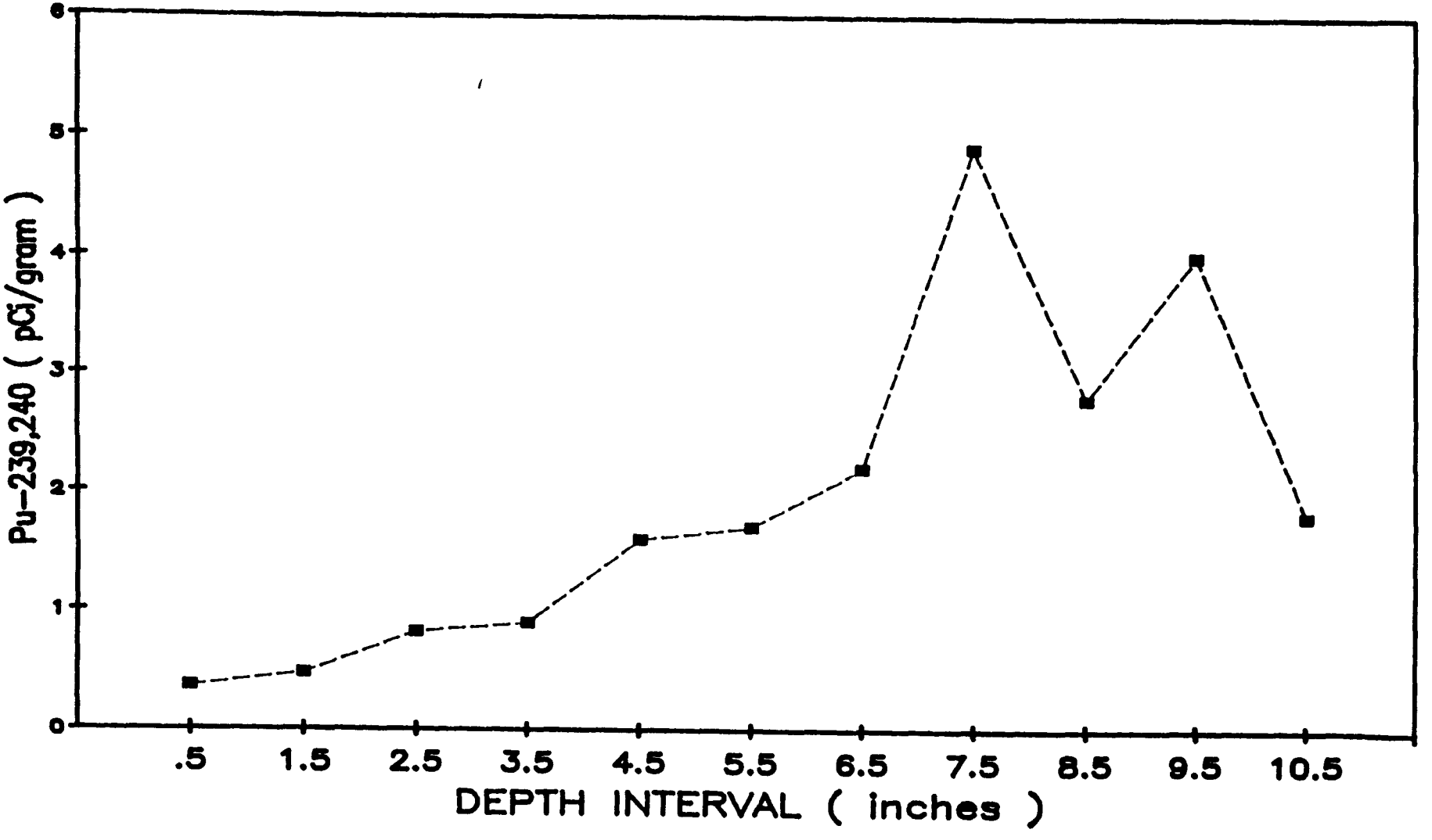
* ANALYSES BY ACCULABS

GREAT WESTERN RESERVOIR — CORE KB3
PLOT OF Pu–239,240 vs. SEDIMENT DEPTH
CITY OF BROOMFIELD *



* ANALYSES BY ACCULABS

GREAT WESTERN RESERVOIR — CORE KB4
PLOT OF Pu–239,240 vs. SEDIMENT DEPTH
CITY OF BROOMFIELD *



* ANALYSES BY ACC[illegible]BS

Rockwell International
Rocky Flats Plant

GREAT WESTERN RESERVOIR STUDY

GEORGE H. SETLOCK
HEALTH, SAFETY AND ENVIRONMENT

Rockwell International
Rocky Flats Plant

GREAT WESTERN RESERVOIR STUDY

- **TOPICS TO BE DISCUSSED**
  - —OVERVIEW OF GWR STUDY
  - —GEOCHEMICAL RESULTS
  - —SUMMARY OF PREVIOUS GWR ENVIRONMENTAL STUDIES

Rockwell International

GREAT WESTERN RESERVOIR STUDY

- OVERVIEW OF GWR 1983 STUDY
  - —SAMPLING METHODOLOGY
    - WATER COLUMN
    - SURFICIAL SEDIMENT (EKMAN GRAB)
    - SEDIMENT CORES (GRAVITY AND PISTON)
    - SEDIMENT TRAP (LLST)
  - —SAMPLING SITES
    - INFRARED RANGE FINDER
    - SITES (WATER COLUMN, GRABS, CORES, SEDIMENT TRAP)

Rockwell International
Rocky Flat Plant

RESERVOIR STUDY

- PREVIOUS STUDIES ON GWR
  - —EPA (1970)
  - —EPA (1973)
  - —BATTELLE (1974)
  - —COMPARISONS WITH PRESENT RFP STUDY

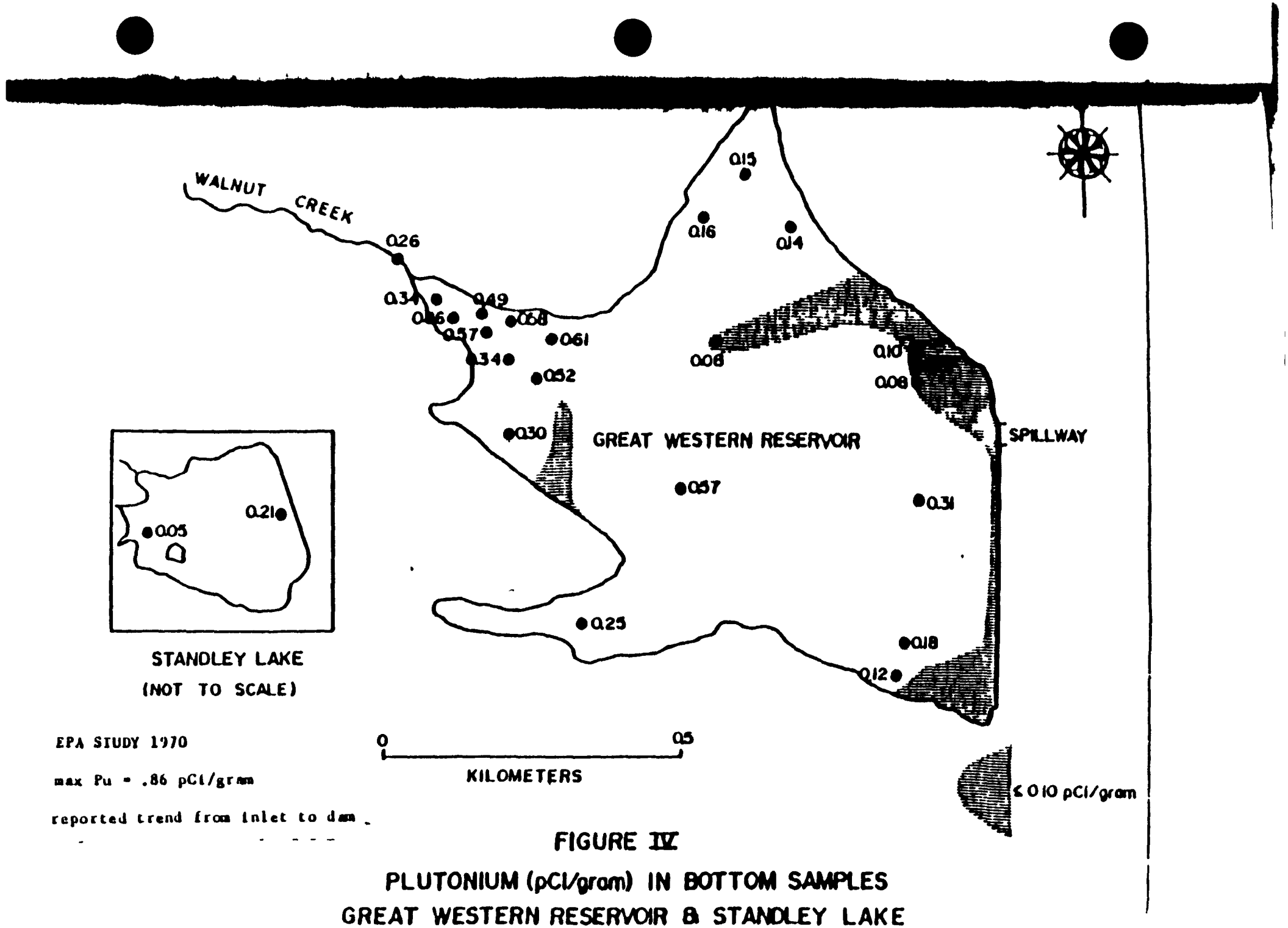
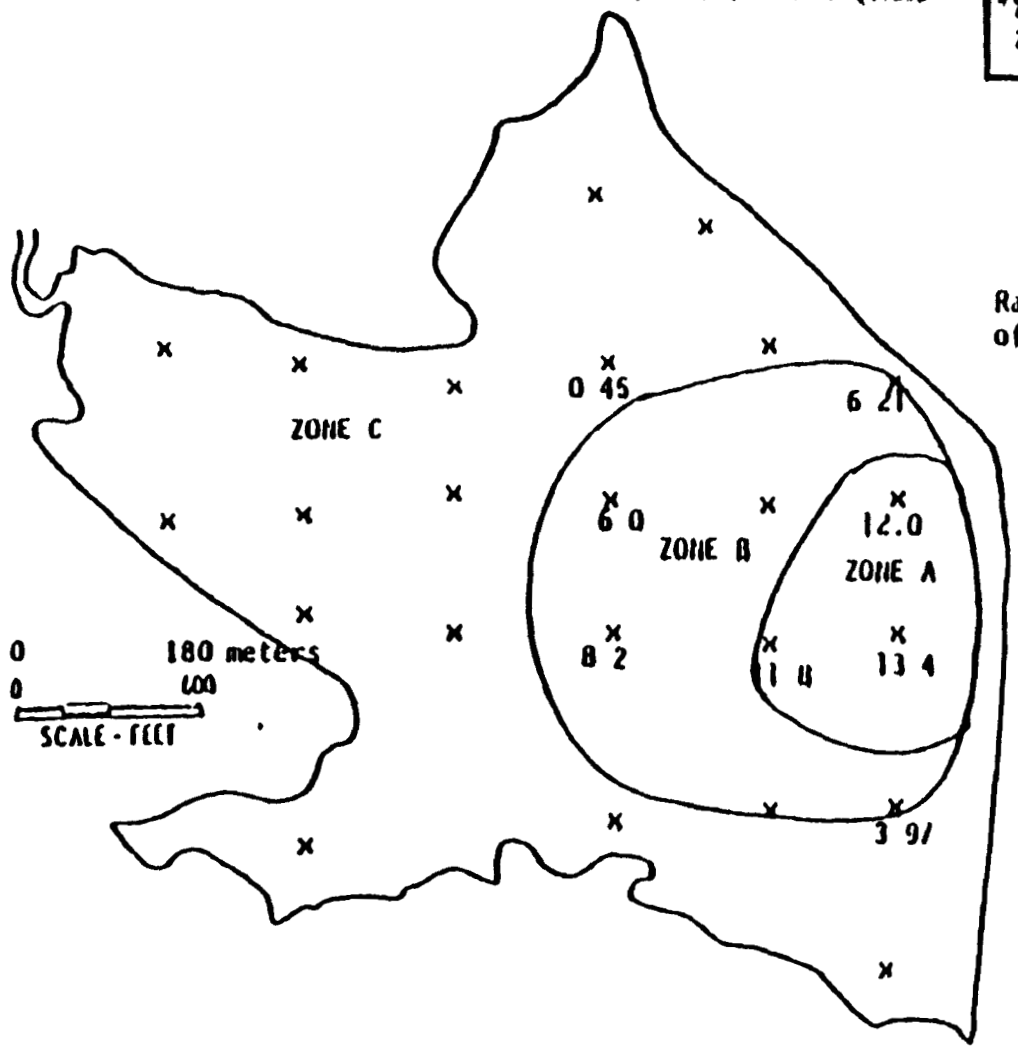


FIGURE IV

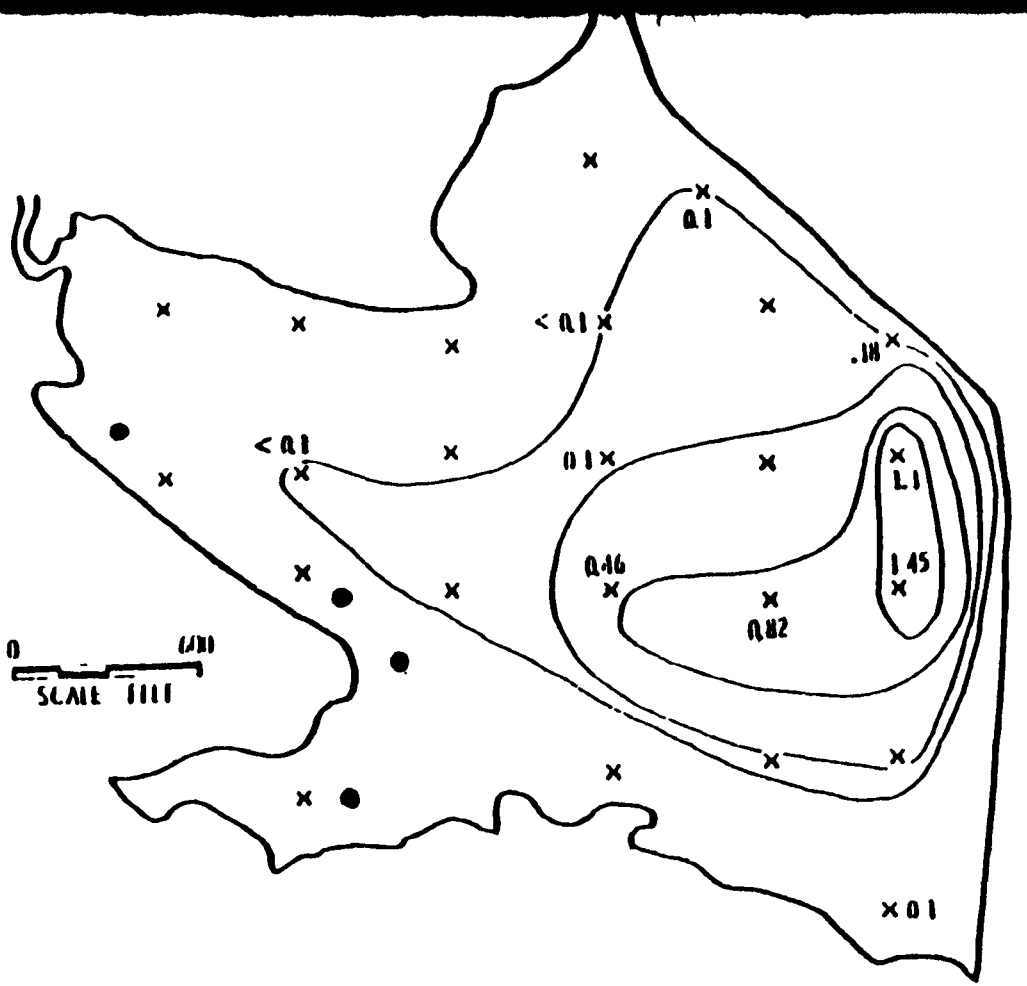
PLUTONIUM (pCi/gram) IN BOTTOM SAMPLES
GREAT WESTERN RESERVOIR & STANDLEY LAKE



ZONE B = 5 dpm/gram
ZONE C = 3 dpm/gram

Range of Pu-239,240 in top 5 0 of GWR sediments = 0 2 - 6.1 pC mean = 3 5 pCi/g

$^{239-240}$Pu Distribution in Surface (0-5 cm) Sediments in Great Western Reservoir and Zones Used for Estimating $^{239-240}$Pu Inventory in Sediments



Deposition Rate of Sediments in Great Western Reservoir (inches/year)

This is an advance copy
a copy for the state
Westminster will be
seen officially to file
for transmittal.

ble
5/28/84

Sample Collection Sampling

STANDLEY LAKE SEDIMENT STUDY

AUGUST, 1984

ROCKWELL INTERNATIONAL
GEORGE SETLOCK
MARK PARICIO
HS&E ENVIRONMENTAL ANALYSIS & CONTROL
SEPTEMBER, 1984

SAMPLE COLLECTION SUMMARY
for the
STANDLEY LAKE PROJECT

On the dates between 7/31/84 and 8/9/84, members of the Environmental Analysis group under the direction of Dr. George Setlock, collected sediment grabs, water samples, and cores from Standley Lake, located southeast of Rocky Flats Plant. The lake was divided into four quadrants, A, B, C, and D from which grids of samples were taken. The exact location of each sample was directed and determined by A. Quintana of the Civil Engineering group using surveying techniques. All samples were recorded in a log book along with their location, time and date, sample type, sampler, and any comments applicable to the particular sample.

Sediment grabs were collected on all days of the sampling period. 51 grabs were taken at predetermined sites from 7/31 to 8/7/84. On 8/8/84, five additional grabs were taken at areas which had been left unrepresented by the predetermined grab locations. On 8/9/84, representatives from the City of Westminster joined the Rockwell team and collected grabs at seven locations of their determination using Rockwell equiptment. Overall, the deepest grab was taken at 86′ 5" (SL-10, 8/3/84), the most shallow grab at 2′ 6" (SL-56, 8/8/84). Two quarts of wet sediment were taken at each location except the Westminster sites where one quart of wet sediment was taken.

Three water samples were taken, all on 8/8/84. A location in Quadrant A was sampled at three depths to compose the water samples. The total depth of the sample location was 73′ 9". Water samples were taken from depths of one foot (surface sample), 37 feet (mid sample), and 70 feet (bottom sample). Two gallons of water were taken at each location.

Four core samples were collected. Two cores were taken on 8/8/84 by the Rockwell team. The two additional cores were taken in conjunction with the City of Westminster on 8/9/84. The maximum depth from which cores were drawn was 84′ 5" (SLKB-2, 8/8/84). The minimum depth was 68′ 0" (SLWM-60, 8/9/84). The cores were of various lengths, reflecting each location's susceptibility to the core sampling technique.

Standley Lake Grab Samples

Grab #	Date Mo/Day/84	Time Hr Min	Depth Ft.In
SL-1	8/2	12 55	8.00
SL-2	8/2	13 16	16.06
SL-3	8/3	9.40	30.00
SL-4	8/3	9 50	44.03
SL-5	8/6	9 22	51.08
SL-6	8/2	11 30	18.04
SL-7	8/2	13.30	34.03
SL-8	8/3	9.20	43.06
SL-9	8/3	10 00	79.04
SL-10	8/3	14·40	86.05
SL-11	8/6	9 33	61.11
SL-12	8/6	11 15	27.03
SL-13	8/2	10 00	14.08
SL-14	8/2	13 45	36.03
SL-15	8/2	14·10	46.10
SL-16	8/3	10.25	74.00
SL-17	8/3	14 20	64.00
SL-18	8/6	9·45	64.01
SL-19	8/6	10.43	30.08
SL-20	8/2	9·45	9.04

Grab #	Date Mo/Day/84	Time Hr:Min	Depth Ft.In
SL-21	8/1	14.30	38.03
SL-22	8/1	14:00	30.09
SL-23	8/3	10 55	60.10
SL-24	8/3	14·10	51.06
SL-25	8/6	10.16	51.07
SL-26	8/6	10 35	13.04
SL-27	8/1	10 45	21.11
SL-28	8/1	11.45	27.02
SL-29	8/3	13.45	64.06
SL-30	8/3	13 37	38.05
SL-31	8/3	13.30	25.11
SL-32	8/3	12 20	13.05
SL-33	8/1	10 10	27.05
SL-34	8/1	9 50	23.02
SL-35	8/7	10.41	50.07
SL-36	8/7	10.27	42.00
SL-37	8/3	12.50	20.08
SL-38	8/7	8 20	16.04
SL-39	7/31	11.35	17.02
SL-40	8/1	9:23	20.04

Grab #	Date Mo/Day/84	Time Hr:Min	Depth Ft.In
SL-41	8/7	10 56	40.09
SL-42	8/7	11·18	35.11
SL-43	8/7	11 41	17.05
SL-44	7/31	11·18	27.08
SL-45	7/31	11.04	25.03
SL-46	8/7	14 13	22.06
SL-47	8/7	14 30	22 01
SL-48	8/7	12 31	15.02
SL-49	8/7	13 59	12.10
SL-50	8/7	13.42	7.03
SL-51	8/7	13 20	8.00
SL-52	8/8	12·05	84.05
SL-53	8/8	13 15	48.08
SL-54	8/8	13 45	61.01
SL-55	8/8	14 02	35.00
SL-56	8/8	14 23	2.06

Standley Lake Grab Samples

taken
in conjunction with
the
City of Westminster

Grab #	Date Mo/Day/84	Time Hr Min	Depth Ft.In
SLWM-10	8/9	9 09	69.07
SLWM-10A	8/9	9.45	81.00
SLWM-20	8/9	11 25	53.00
SLWM-30	8/9	11 00	11.00
SLWM-40	8/9	13·17	11.07
SLWM-50	8/9	12 58	17.00
SLWM-60	8/9	12 10	68.00

Standley Lake Water Samples

Sample Name	Date Mo/Day/84	Time Hr Min	Depth Ft.In
Surface	8/8	10 09	1.00
Mid	8/8	10·25	37.00
Bottom	8/8	10 30	70.00

Standley Lake Core Samples

Core #	Date Mo/Day/84	Time Hr Min	Depth Ft.In
SLKB-1	8/8	11 18	77.00
SLKB-2	8/8	11.50	84.05
*SLWM-10A	8/9	10 34	81.00
*SLWM-60	8/9	12:10	68.00

*
Denotes cores taken in conjunction with the City of Westminster.

OCT 3 1984

City of Westminster
c/o Kelly DiNatale
3031 West 76th Avenue
Westminster, Colorado 80030

Dear Mr. DiNatale:

Attached is a sediment sample location map and short report describing Rockwell's sampling activities conducted on Standley Lake in August, 1984. All of the sediment samples collected from Standley Lake are being processed for plutonium analyses by our RS&E 123 laboratory. These data will be shared with and presented at a State Exchange meeting in Spring, 1985. Future correspondence will keep you aware of progress on the radiochemical data acquisition and reporting schedule.

Sincerely,

Original Signed By
James R. Nicks
Area Manager

Attachment

S+E file cy

S&E BR	S&E BR	DAM	AREA MGR
Crist.ld	Stearns	Bellows	Nicks
10/1/84	10/1/84	10/ /84	10/ /84

City of Thornton
c/o Mark Speed
9500 Civic Centre Drive
Thornton, Colorado 80229

Dear Mr. Speed:

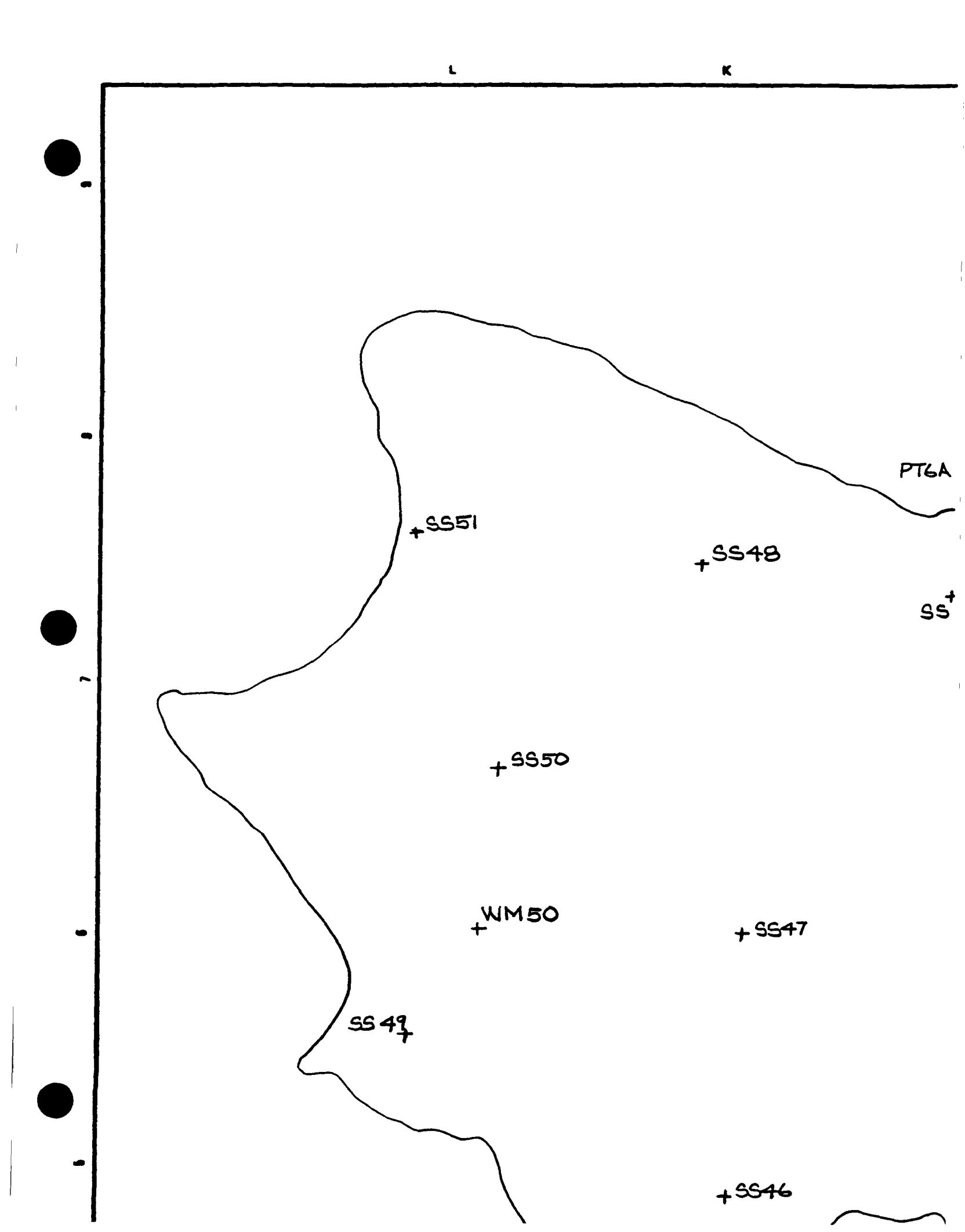
Attached is a sediment sample location map and short report describing Rockwell's sampling activities conducted on Standley Lake in August, 1984. All of the sediment samples collected from Standley Lake are being processed for plutonium analyses by our USSF 123 laboratory. These data will be shared with and presented at a State Exchange meeting in Spring, 1985. Future correspondence will keep you aware of progress on the radiochemical data acquisition and reporting schedule.

Sincerely,

James R. Nicks
Area Manager

Attachment

S&E BR	S&E BR	DAM	AREA MGR
Cristield	Stearns	Bellows	Nicks
10/1/84	10/1/84	10/ /84	10/ /84


L
K
PT6A
SS51
SS48
SS
SS50
WM50
SS47
SS49
SS46

PT 1

ISSUE	DESCRIPTION	DATE	RFP	DOE	CLASS	JOB NO
A	ORIGINAL ISSUE		QU			430022

	BY	DATE
DESIGNED		
DRAWN	QUINTANA	8-22-83
CHECKED		
APPROVED		
SUBMITTED		
APPROVED RFP		
APPROVED DOE		

TOLERANCES
FRACT ±
ANGLE ±
DEC ±
UNLESS NOTED OTHERWISE

REMOVE BURRS AND SHARP EDGES

NEXT ASSEMBLY

SCALE NOTED

U.S. DEPARTMENT OF ENERGY
ROCKY FLATS AREA OFFICE GOLDEN COLORADO

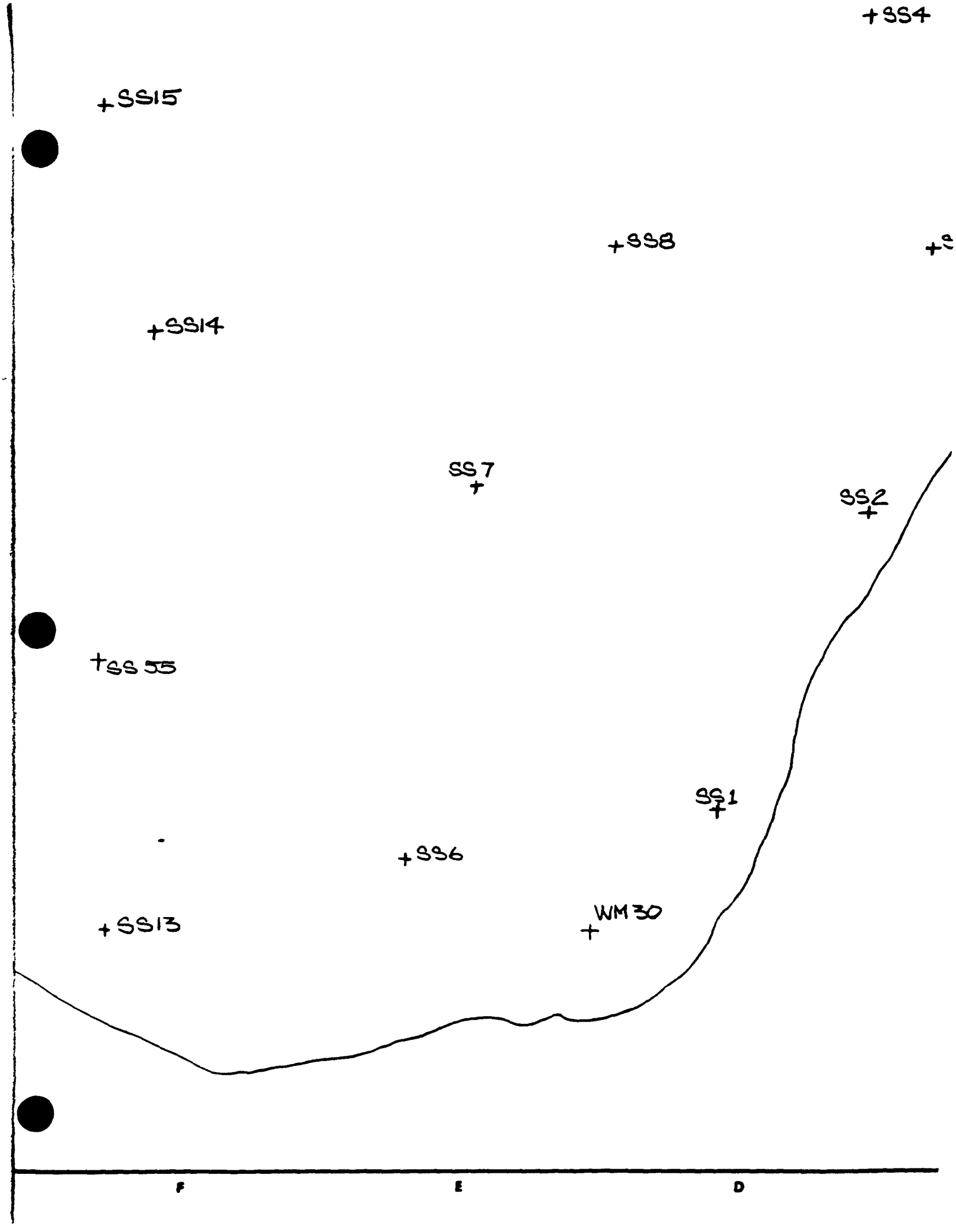
Rockwell International
ROCKY FLATS PLANT
ENERGY SYSTEMS GROUP
GOLDEN, COLORADO 80401

STANDLEY LAKE
SAMPLE LOCATION PLAN

SIZE	DRAWING NUMBER	ISSUE	SHEET
D	SK430022-2	A	OF

BLDG FAC
ROOM AREA
M Mfg-Vent
A Arch
G GL Bar
E Elec
D Detection
M Mech
I Inst
S Sit-Canc
C Cond
U Utilities
P Piping
W Fire Prot
L Layouts
F Flow Diag
S Site
X Alarms

C B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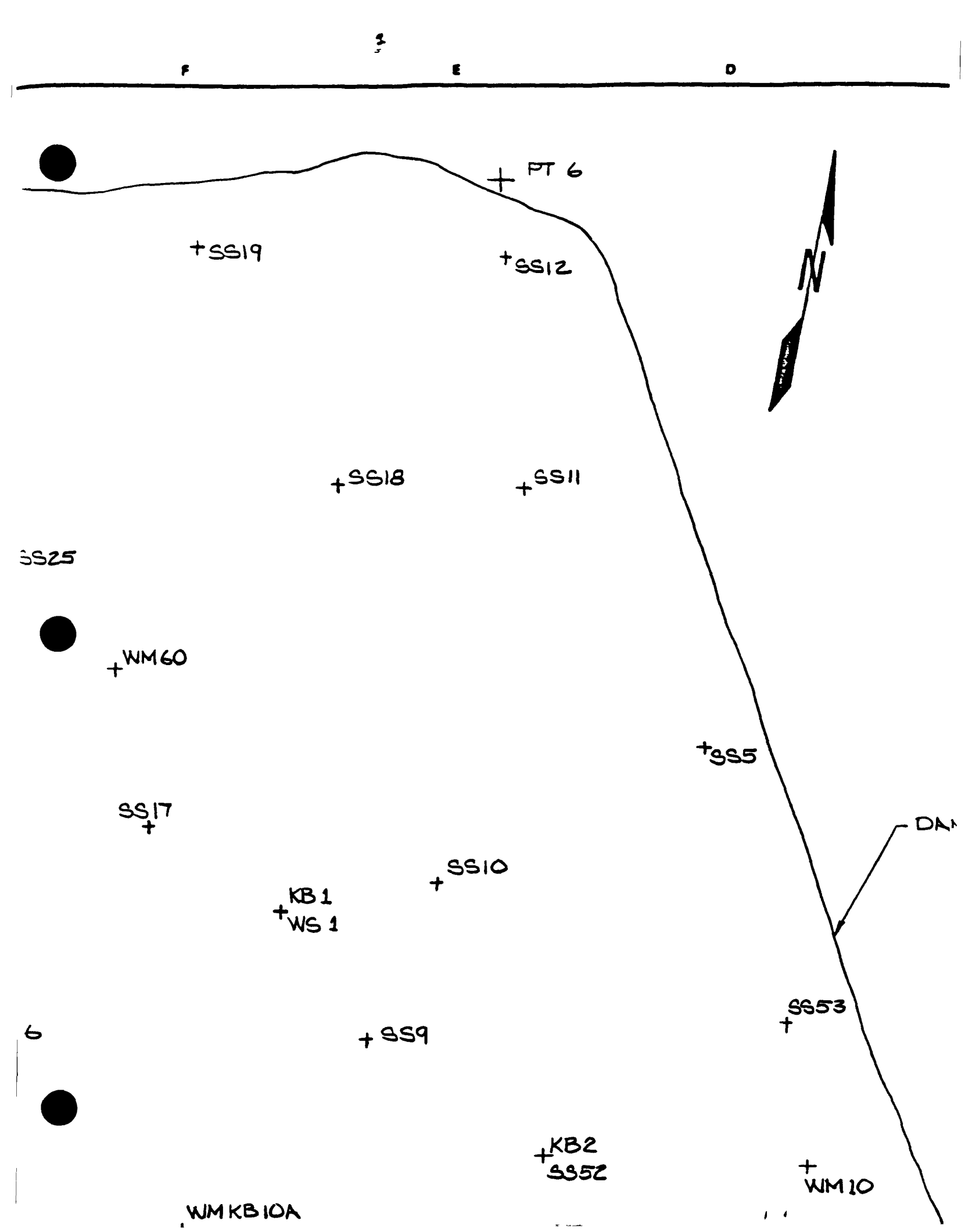
+SS 55
SS1
+SS6
WM30
+SS13
F
E
D

F E D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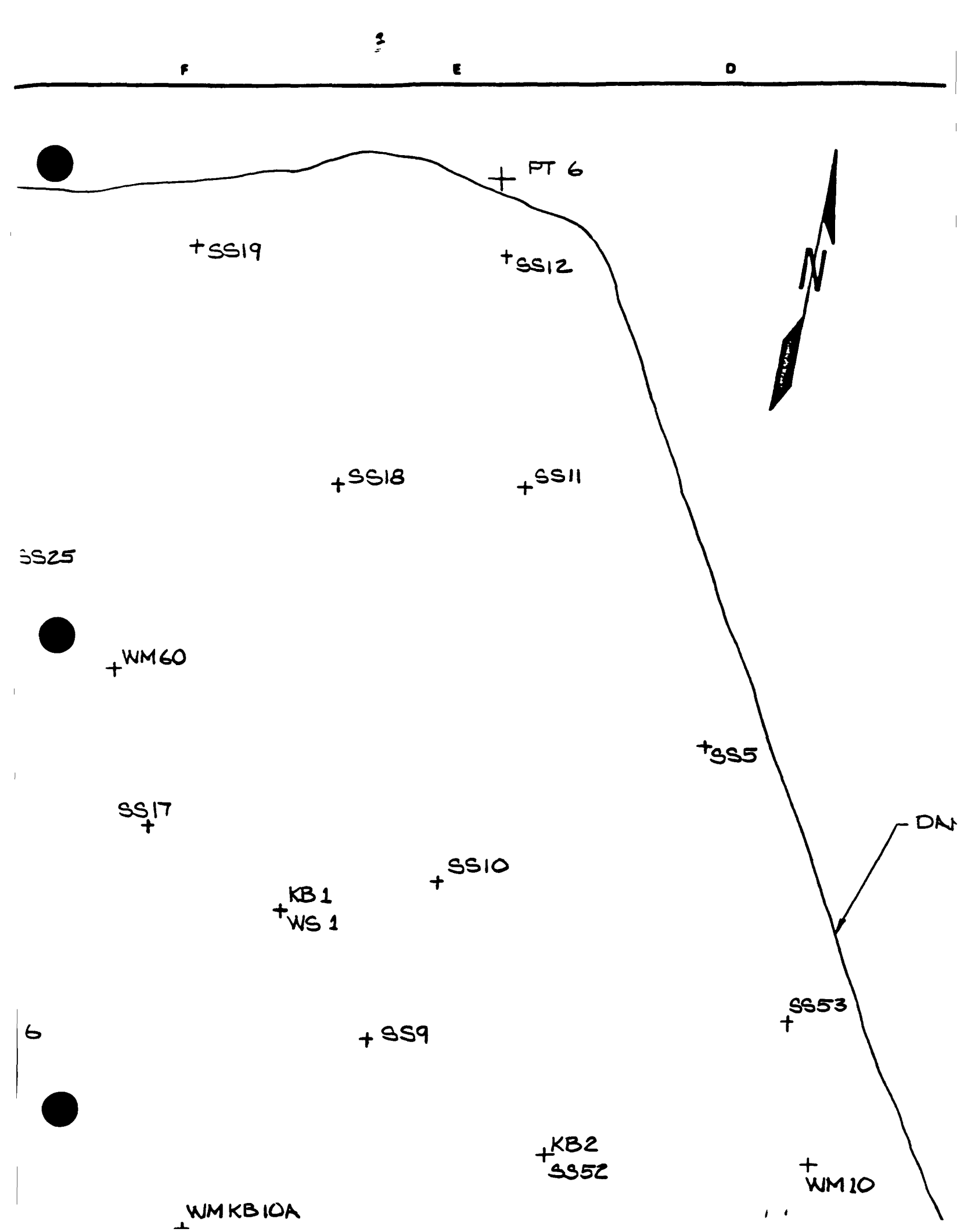
SS19
SS12
N
SS18
SS11
SS25
WM60
SS5
SS17
DA
SS10
KB 1
WS 1
SS53
6
SS9
KB2
SS52
WM10
WM KB10A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E
D
PT 6
SS19
SS12
N
SS18
SS11
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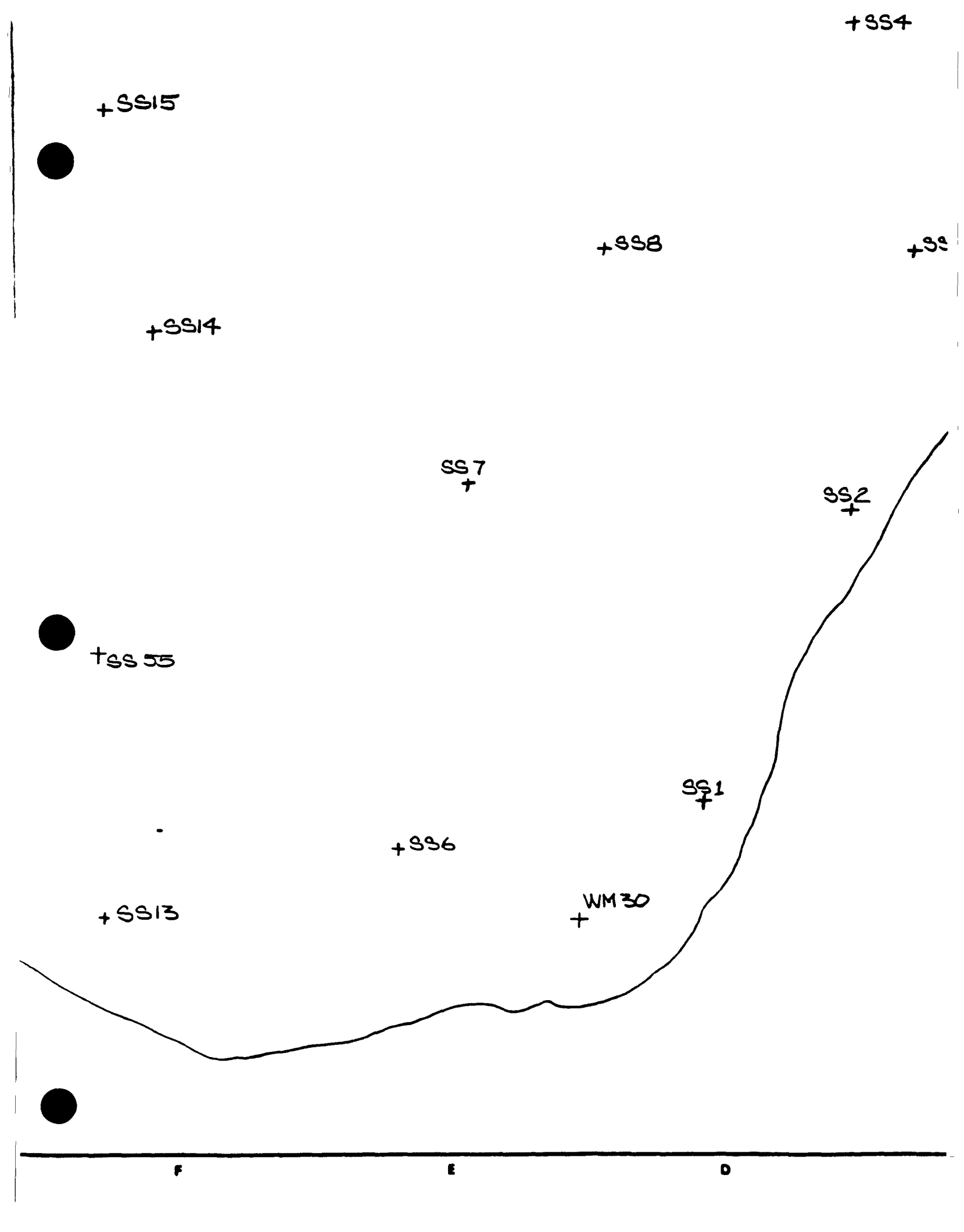
SS53
6
SS9
KB2
SS52
WM10
WM KB10A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+SS15
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+SS14
SS7
SS2
SS 55
SS1
+SS6
WM30
+SS13
F
E
D

PART	QUAN	DESCRIPTION	MATERIAL

LEGEND

PT	SURVEY POINT
SS	SEDIMENT GRAB SAMPLE
WS	WATER SAMPLE
KB	GRAVITY CORE SAMPLE
WM	WESTMINSTER GRAB

PT 1

ISSUE	DESCRIPTION	DATE	RFP	DOE	CLASS	JOB NO
A	ORIGINAL ISSUE		QU			430022

TOLERANCES
FRACT ±
ANGLE ±
DEC. ±
UNLESS NOTED OTHERWISE

REMOVE BURRS AND SHARP EDGES

NEXT ASSEMBLY

SCALE NOTED

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DRAWN	QUINTANA	8-22-83
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U.S. DEPARTMENT OF ENERGY
ROCKY FLATS AREA OFFICE GOLDEN COLORADO

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ROCKY FLATS PLANT
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GOLDEN, COLORADO 80401

STANDLEY LAKE
SAMPLE LOCATION PLAN

SIZE	DRAWING NUMBER	ISSUE	SHEET
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BLDG FAC
ROOM AREA
H Htg-Vent
A Arch
G GL Bas
E Elec
D Detection
M Mech
I Inst
S Sit-Conc
C Civil
U Utilities
P Piping
W Fire Prot
L Layouts
F Flow Diag
S Sites
X Alarms

C B

STANDLEY LAKE SEDIMENT STUDY

SUMMARY

- ROCKWELL'S 1984 STUDY OF STANDLEY LAKE SEDIMENTS UPDATED STUDIES CONDUCTED BY EPA/BATTELLE IN 1970'S.

- LEVELS OF PLUTONIUM IN SEDIMENTS HAVE REMAINED AT LOW LEVELS CONSISTENT WITH ATMOSPHERIC FALLOUT (1950-70'S WEAPONS TESTS)

- NATURALLY OCCURRING RADIUM-226 CONCENTRATIONS ARE 100-1000X THOSE OF Pu-239 AND REPRESENT A GREATER CONTRIBUTION TO PUBLIC RADIATION EXPOSURE THAN THE TRACES OF PLUTONIUM-239 (BATTELLE-1974)

POST STUDIES

- EPA conducted a sediment study in September, 1970.
  Scope - 2 surface grabs + 2 sediment cores
  Maximum Pu-239 concentration = .37 pCi/gram

- EPA conducted another sediment study in September, 1973.
  Expanded scope - 17 surface grabs + 8 sediment cores
  Maximum Pu-239 concentration = .17 pCi/gram

- Battelle's Pacific Northwest Lab conducted a sediment study in May, 1974.
  Scope - 8 surface grabs
  Maximum Pu-239 concentration = .29 pCi/gram

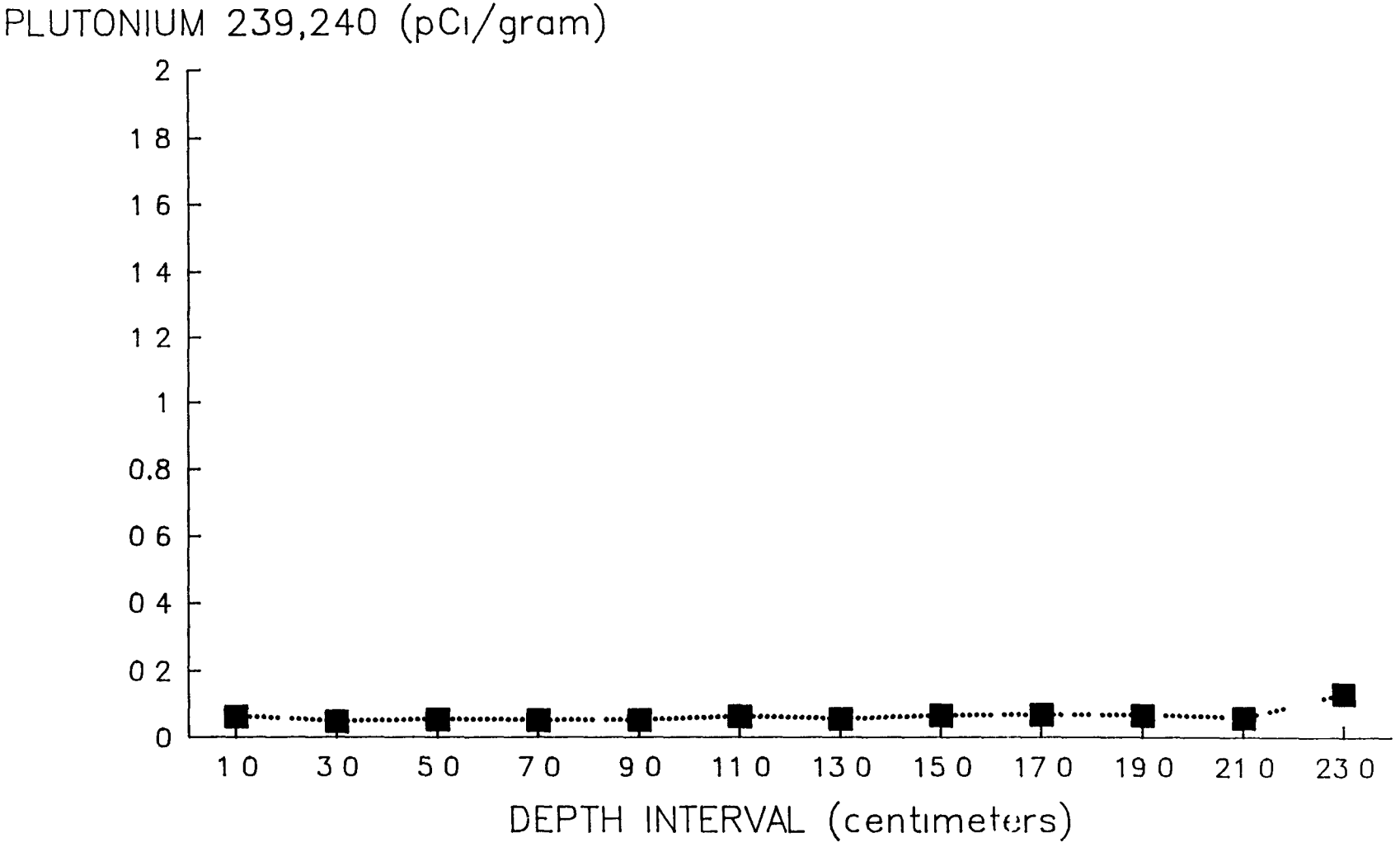
ROCKWELL STUDY

- Rockwell conducted a sediment study to update previous Standley Lake studies in August, 1984.
  Scope - 63 surface grabs + 2 sediment cores
  Maximum Pu-239 concentration = .61 pCi/gram

12

STANDLEY LAKE SEDIMENT CORE SAMPLE KB2

PLOT OF Pu-239, 240 VS SEDIMENT DEPTH



RI STANDLEY LAKE SEDIMENT STUDY (8/84)
CDH CONSTRUCTION STANDARD = 1 0 pCi/gram

STANDLEY LAKE SEDIMENT CORE SAMPLE KB1
PLUTONIUM 239,240 ANALYTICAL RESULTS

	ROCKY FLATS LAB #	% RECOVERY OF RADIOTRACER SPIKE	Pu-239, 240 (pCi/gram)
SL-KB1A (0 - 2 cm)	85002361	55	054 +/- 007
SL-KB1B (2 - 4 cm)	85002362	74	109 +/- 013
SL-KB1C (4 - 6 cm)	85002363	58	075 +/- 010
SL-KB1D (6 - 8 cm)	85002364	61	084 +/- 009
SL-KB1E (8 -10 cm)	85002365	51	065 +/- 008
SL-KB1F (10 -12 cm)	85002366	73	068 +/- 009
SL-KB1G (12 -14 cm)	85002367	60	105 +/- 014
SL-KB1H (14 -16 cm)	85002368	42	097 +/- 011
SL-KB1I (16 -18 cm)	85002369	57	607 +/- 056
SL-KB1J (18 -20 cm)	85002370	61	388 +/- 042
SL-KB1K (20 -22 cm)	85002371	56	244 +/- 025

SEDIMENT SAMPLES COLLECTED IN AUGUST, 1984

STANDLEY LAKE SEDIMENT CORE SAMPLE KB2

PLUTONIUM 239,240 ANALYTICAL RESULTS

	ROCKY FLATS LAB #	% RECOVERY OF RADIOTRACER SPIKE	Pu-239, 240 (pCi/gram)
SL-KB2A (0 - 2 cm)	85002372	55	064 +/- 008
SL-KB2B (2 - 4 cm)	85002373	72	049 +/- 007
SL-KB2C (4 - 6 cm)	85002374	51	055 +/- 007
SL-KB2D (6 - 8 cm)	85002375	48	052 +/- 007
SL-KB2E (8 -10 cm)	85002376	46	053 +/- 007
SL-KB2F (10 -12 cm)	85002377	46	064 +/- 008
SL-KB2G (12 -14 cm)	85002378	51	056 +/- 007
SL-KB2H (14 -16 cm)	85002379	58	067 +/- 009
SL-KB2I (16 -18 cm)	85002380	55	069 +/- 009
SL-KB2J (18 -20 cm)	85002381	59	067 +/- 008
SL-KB2K (20 -22 cm)	85002382	49	059 +/- 009
SL-KB2L (22 -24 cm)	85002383	37	132 +/- 015

SEDIMENT SAMPLES COLLECTED IN AUGUST, 1984

STANDLEY LAKE SURFICIAL SEDIMENT SAMPLES
PLUTONIUM 239,240 ANALYTICAL RESULTS

	ROCKY FLATS LAB #	% RECOVERY OF RADIOTRACER SPIKE	Pu-239, 240 (pCi/gram)
SL-1	29472	56	000 +/- 110
SL-2	29473	57	000 +/- 110
SL-3	29474	63	002 +/- 099
SL-4	29475	75	008 +/- 074
SL-5	29476	65	024 +/- 004
SL-6	29477	62	000 +/- 110
SL-7	29478	69	018 +/- 025
SL-8	29479	53	029 +/- 012
SL-9	29480	67	041 +/- 012
SL-10	29481	63	050 +/- 013
SL-11	29482	42	046 +/- 015
SL-12	29483	73	005 +/- 088
SL-13	29484	95	005 +/- 092
SL-14	29485	73	024 +/- 005
SL-15	29486	65	014 +/- 047
SL-16	29487	76	048 +/- 013
SL-17	29488	78	057 +/- 013
SL-18	29489	66	030 +/- 012
SL-19	29490	66	017 +/- 031
SL-20	29491	81	000 +/- 100
SL-21	29492	66	092 +/- 017

SEDIMENT SAMPLES COLLECTED IN AUGUST, 1984

STANDLEY LAKE SURFICIAL SEDIMENT SAMPLES
PLUTONIUM 239,240 ANALYTICAL RESULTS

	ROCKY FLATS LAB #	% RECOVERY OF RADIOTRACER SPIKE	Pu-239, 240 (pCi/gram)
SL-22	29493	59	014 +/- 046
SL-23	29494	87	068 +/- 014
SL-24	29495	92	067 +/- 014
SL-25	29498	62	026 +/- 011
SL-26	29499	46	018 +/- 029
SL-27	29500	49	018 +/- 034
SL-28	29501	74	018 +/- 032
SL-29	29502	58	067 +/- 015
SL-30	29503	40	069 +/- 016
SL-31	29504	51	028 +/- 011
SL-32	29505	72	012 +/- 053
SL-33	29506	64	014 +/- 048
SL-34	29507	86	045 +/- 012
SL-35	29508	74	553 +/- 046
SL-36	29509	67	100 +/- 017
SL-37	29510	65	023 +/- 001
SL-38	29511	77	020 +/- 015
SL-39	29512	68	000 +/- 110
SL-40	29513	59	014 +/- 048
SL-41	29514	81	061 +/- 013
SL-42	29515	86	079 +/- 014

SEDIMENT SAMPLES COLLECTED IN AUGUST, 1984

STANDLEY LAKE SURFICIAL SEDIMENT SAMPLES
PLUTONIUM 239,240 ANALYTICAL RESULTS

	ROCKY FLATS LAB #	% RECOVERY OF RADIOTRACER SPIKE	Pu-239 240 (pCi/gram)
SL-43	29516	61	018 +/- 025
SL-44	29517	91	063 +/- 013
SL-45	29518	73	071 +/- 014
SL-46	29519	65	022 +/- 008
SL-47	29520	70	041 +/- 012
SL-48	29521	76	047 +/- 012
SL-49	31930	73	- 012 +/- 059
SL-50	31931	66	003 +/- 012
SL-51	31932	54	063 +/- 017
SL-52	31933	62	027 +/- 013
SL-53	31934	62	- 013 +/- 065
SL-54	31935	92	029 +/- 013
SL-55	31936	82	024 +/- 012
SL-56	31937	51	- 015 +/- 074
SLWM-10	31941	66	062 +/- 016
SLWM-10A	31942	61	028 +/- 013
SLWM-20	31943	81	015 +/- 006
SLWM-30	31944	76	- 015 +/- 076
SLWM-40	31945	38	- 004 +/- 024
SLWM-50	31946	32	- 011 +/- 057
SLWM-60	31947	42	025 +/- 013

SEDIMENT SAMPLES COLLECTED IN AUGUST, 1984

PLUTONIUM SOIL STANDARD ANALYSES

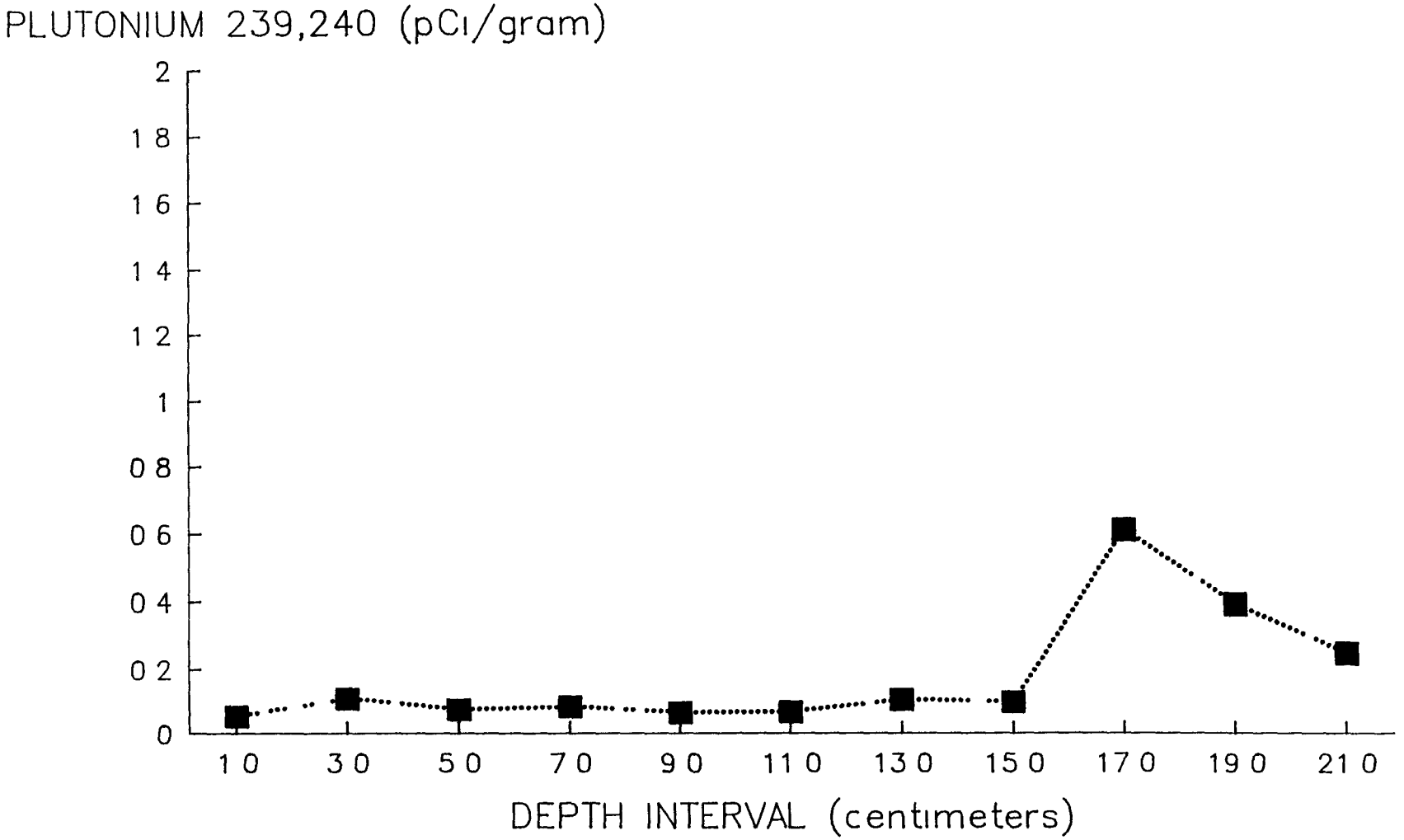
STANDLEY LAKE SEDIMENT STUDY SAMPLES

	ROCKY FLATS LAB #	% RECOVERY OF RADIOTRACER SPIKE	Pu-239, 240 (pCi/gram)
SOIL BLANK	19260	82	− 003 +/− 007
SOIL BLANK	19261	37	− 004 +/− 010
SOIL BLANK	29497	58	− 024 +/− 120
SOIL BLANK	85002386	31	001 +/− 001
SOIL BLANK	85002412	68	003 +/− 002
SOIL STANDARD 601220	19258	81	810 +/− 056
SOIL STANDARD 601220	29496	87	830 +/− 059
SOIL STANDARD 601220	31949	75	870 +/− 066
SOIL STANDARD 601220	85002384	61	893 +/− 070
SOIL STANDARD 601220	85002410	83	938 +/− 078
SOIL STANDARD 601221	19259	76	3 100 +/− 190
SOIL STANDARD 601221	29522	86	3 200 +/− 200
SOIL STANDARD 601221	31950	78	3 000 +/− 210
SOIL STANDARD 601221	85002385	67	3 381 +/− 248
SOIL STANDARD 601221	85002411	76	3 637 +/− 365

RFP Pu SOIL STDS PREPARED FROM NBS PRIMARY STD
SOIL STANDARD 601220 = 900 +/− 180
SOIL STANDARD 601221 = 3 514 +/− 090

STANDLEY LAKE SEDIMENT CORE SAMPLE KB1

PLOT OF Pu-239, 240 VS SEDIMENT DEPTH

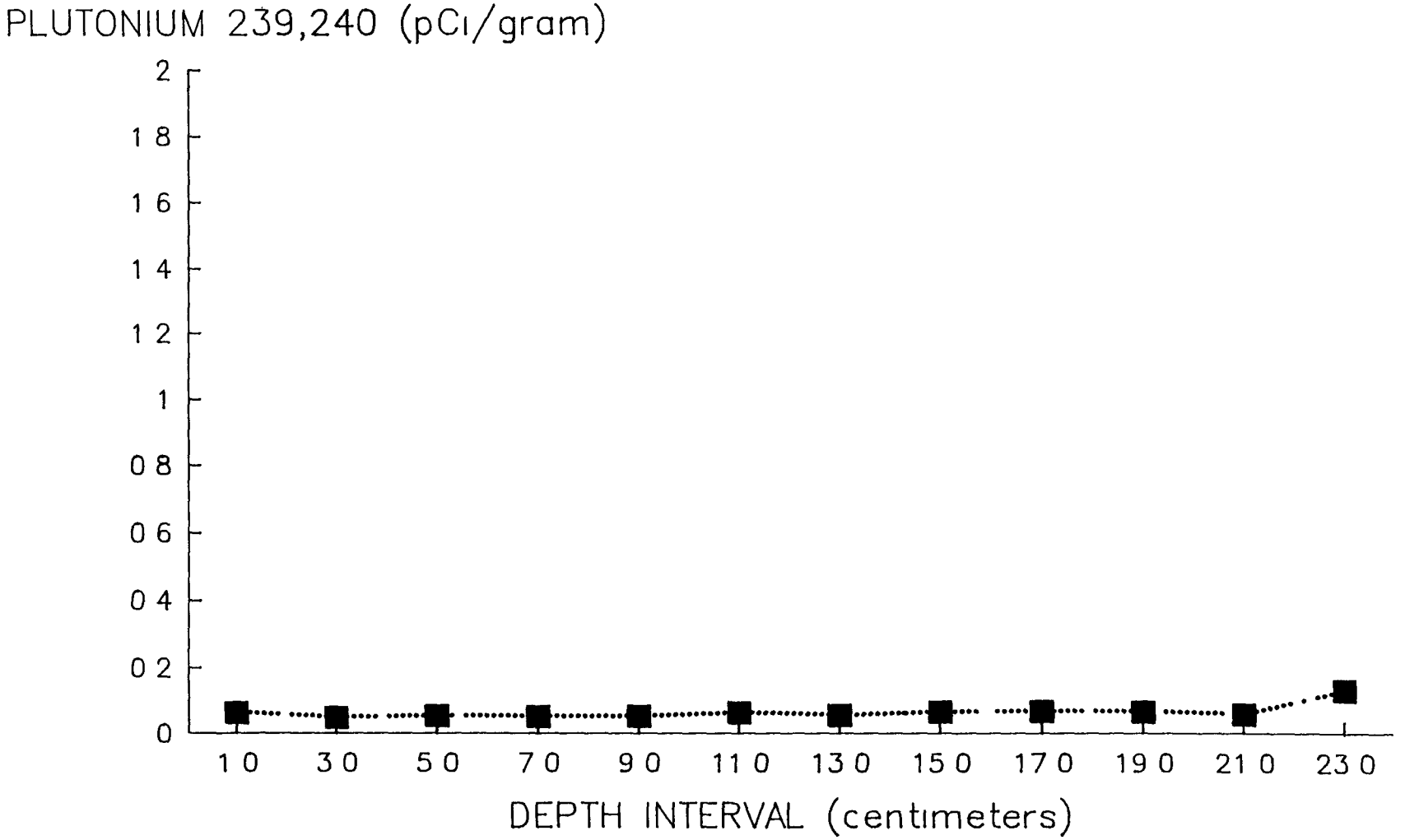


[illegible] (pCi/gm)

[illegible] 1.0 pCi/gram

STANDLEY LAKE SEDIMENT CORE SAMPLE KB2

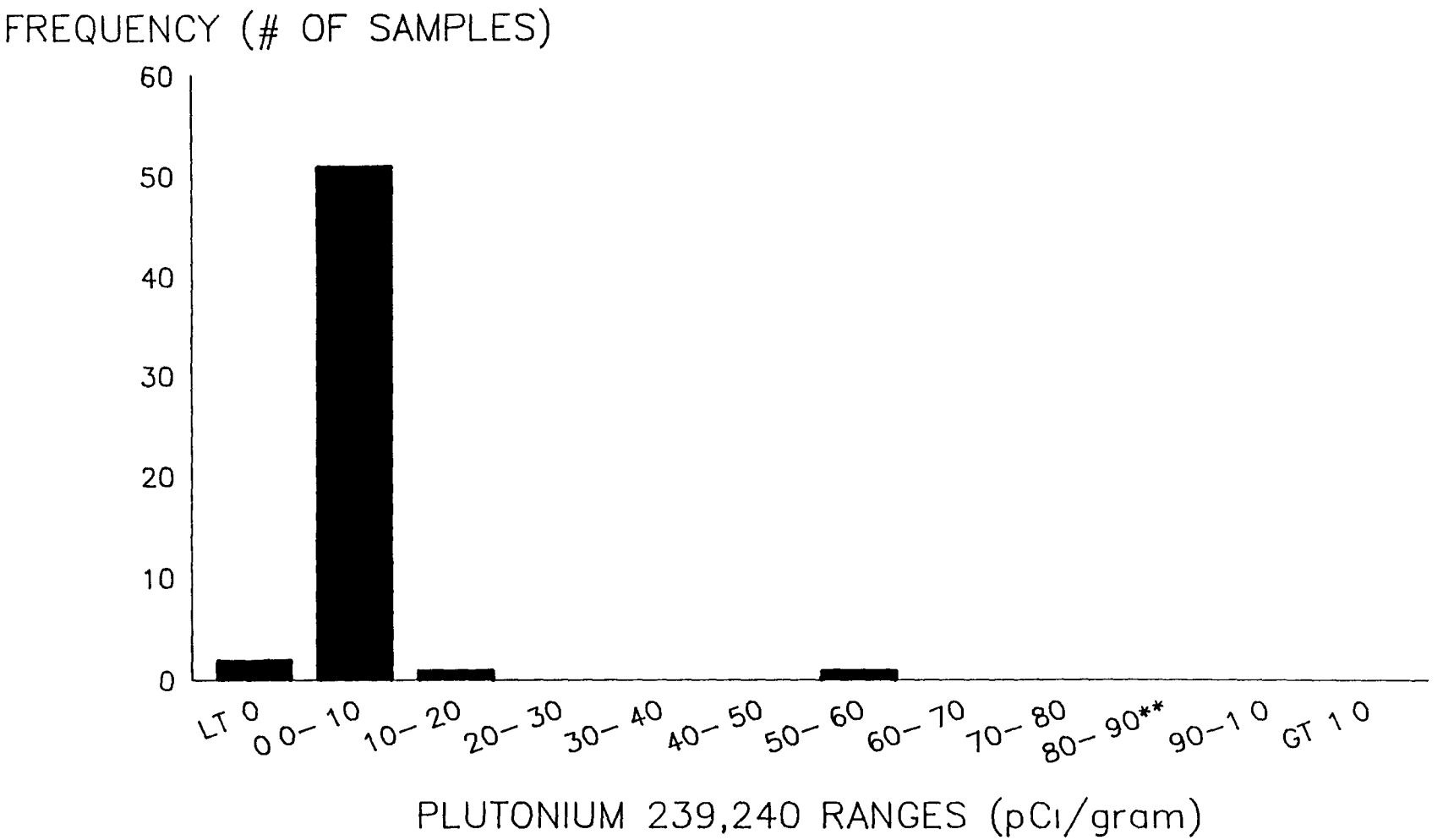
PLOT OF Pu-239, 240 VS SEDIMENT DEPTH



RI STANDLEY LAKE SEDIMENT STUDY (8/84)
CDH CONSTRUCTION STANDARD = 1 0 pCi/gram

STANDLEY LAKE SURFICIAL SEDIMENT SAMPLES

PLUTONIUM 239, 240 CONCENTRATION DISTRIBUTION



RI STANDLEY LAKE SEDIMENT STUDY (8/84)
TOTAL SURFICIAL SAMPLES COLLECTED = 63
** CDH Pu CONSTRUCTION STD = 0 9 pCi/gram

SUMMARY

The Colorado Department of Health analyzed fish collected from Standley Lake in June, 1989 for a variety of pollutants to determine if these fish were safe for human consumption The species analyzed included walleyes, channel catfish, smallmouth bass and rainbow trout, which were collected by electro-fishing and gillnetting Composites of raw fillets for each species were analyzed for selected metals, radioactive substances and priority organic pollutants Radioactive materials, including plutonium-239+240 and cesium-137, were subjected to exceptionally sensitive analysis and were not detected Low concentrations of cadmium, mercury, selenium, DDT, DDE, DDD and malathion were detected in some or all species Although the source of these contaminants was not determined in this study, none of them are unique to the Rocky Flats Nuclear Weapons Facility They may originate from a variety of sources in the watershed, including water diverted from Clear Creek which contributes ninety-six percent of the flow to the lake

The results of a health risk assessment indicate that consumption of a reasonable quantity of fish from Standley Lake does not present an appreciable health risk to the public, from either a toxicity or cancer-causing standpoint This type of screening survey is generally not undertaken in Colorado unless there is evidence of a known contamination source Therefore, comparative information for other lakes and reservoirs is not available Additional in-depth monitoring at Standley Lake, as well as monitoring of pollutants in fish from other Front Range lakes, should be undertaken to confirm these results and provide comparative information

INTRODUCTION

The June, 1989 Agreement in Principle between the U S Department of Energy and the State of Colorado provides additional funding and resources to the Colorado Department of Health (CDH) to intensify environmental monitoring efforts around the Rocky Flats Nuclear Weapons Facility As part of this increased effort and to address public concern regarding the potential impact from Rocky Flats, CDH conducted a study of fish samples taken from Standley Lake, a water supply reservoir located 3 miles downstream from the plant The primary objective was to determine whether the fish were contaminated by chemical or radioactive pollutants from the facility and, if so, whether they were unsafe for human consumption

The screening level health risk assessment of fish considered three components 1) a hazard identification, 2) a dose-response assessment, and 3) an exposure assessment In the first two components, various chemical, toxicological and radiological data bases were reviewed In the third, the concentration of pollutants in fish tissue and average fish ingestion rates were used to estimate levels of human exposure to contaminants and the corresponding health risks

Although Great Western Reservoir also lies downstream of the Rocky Flats Plant, fish from this reservoir were not analyzed because fishing is not allowed in the reservoir and there is no public access to it

STUDY DESIGN

The primary aim of this investigation was to measure the concentrations of suspected pollutants in edible fish tissue Accordingly, fillets had to be obtained, prepared and cleaned using the same procedures normally employed by most anglers Analysis, therefore, did not include either whole fish or specific organs, such as the liver However, analysis of these tissues may be appropriate for subsequent studies

Given the initial resources available, a screening survey sampling design, patterned on Phase I of the Massachusetts Fish Toxics Monitoring Program (U S EPA 1987), was selected for an expedited assessment during the summer of 1989 That program is a three-phased approach consisting of a screening survey, confirmatory analysis, and follow-up In the Standley Lake study, at least three fish per composite were selected for each species Composite analysis was selected over analysis of individual fish because such a strategy is more cost-effective for screening when the tissue mass required for analysis is large Separate samples for organics and for inorganics (e g , metals and radionuclides) were selected for each species A combined total of eight samples, two each of four species of fish, was analyzed

TARGET SPECIES

Target fish species were chosen to satisfy three criteria (1) that the fish are common and likely to be caught and eaten, (2) that selected species include a bottom feeder and top predator in the aquatic food chain, and (3) that the number of species be limited to four In consultation with the Colorado Division of Wildlife's Central Region fisheries personnel, CDH Water Quality Control Division selected walleye (Stizostedion vitreum), smallmouth bass (Micropterus dolomieui, rainbow trout (Oncorhynchus mykiss) and the channel catfish (Ictalurus punctatus)

Other species in the reservoir include the bluegill, carp, green sunfish, largemouth bass, sucker and yellow perch

SUSPECTED CONTAMINANTS

The list of potential contaminants (Appendix A) selected for analysis was compiled after consultation with CDH personnel from the Environmental Epidemiology, Hazardous Materials and Waste Management, Radiation Control, Laboratory and Water Quality Control Divisions The list includes a priority pollutant scan for organics and metals along with radionuclides potentially released by the Rocky Flats Plant

FISH COLLECTION

Biologists from the Colorado Division of Wildlife and the Colorado Water Quality Control Division collected fish by electrofishing along the dam between approximately 7 pm and 9 30 pm on June 28, 1989 In addition, gill nets were set at three locations on the lake (Figure 1) The Colorado Division of Wildlife personnel selected the sampling sites based on their previous work on the lake The onset of dangerous wind conditions prevented the nets from being checked after 2 to 3 hours Therefore, they were left out overnight, and retrieved between 8 and 9 the following morning

The species collected included walleye, smallmouth bass, rainbow trout, channel catfish, white suckers, carp and yellow perch The largest two walleyes, the carp and the smallmouth bass were captured along the dam by electrofishing The gillnet at site 1 captured trout, perch, carp and smaller walleyes The remaining two gillnets (site 2 and 3) captured trout, small walleyes, white suckers, carp and channel catfish

Captured fish were held temporarily in a thoroughly rinsed metal tub which contained 10 gallons of lake water Live fish were removed from the tub and killed with a sharp blow to the head before processing Subsamples of each species were randomly allocated within size groups into either organics or inorganics analysis Fish destined for organics analysis were wrapped in aluminum foil, those for the metals and radionuclide analysis were placed in

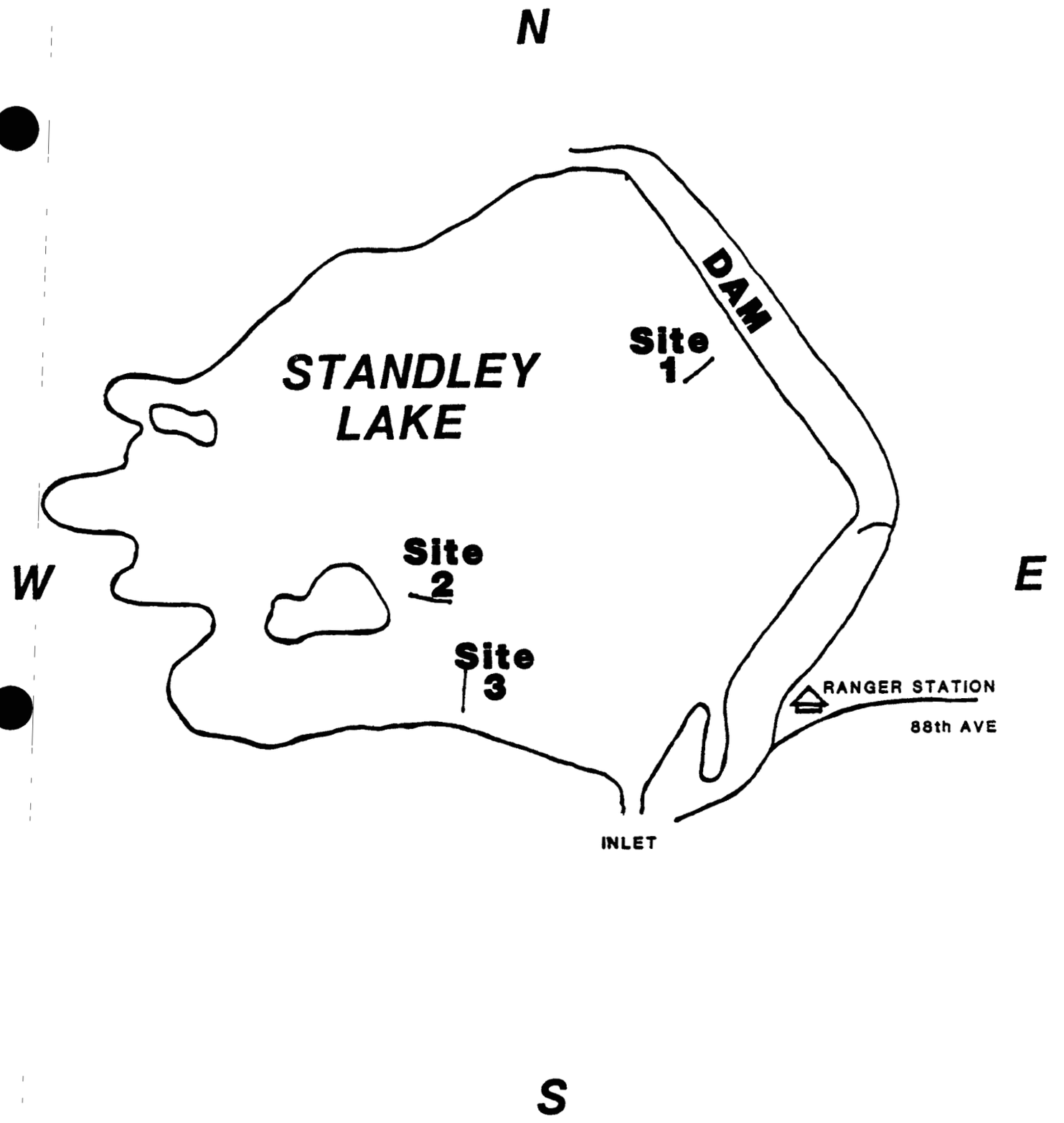


Figure 1 Fish collection locations at Standley Lake Sites 1, 2 and 3 were gillnet sets

plastic bags The fish were labeled and placed on ice, but not frozen, and transported back to the laboratory These procedures are consistent with U S Environmental Protection Agency (EPA) guidance (U S EPA 1989)

The whole body weights and lengths and the fillet weights of the four target species are presented in Table 1 Fillets were collected from six walleyes, six channel catfish, six smallmouth bass and ten rainbow trout Moisture in the homogenized composites ranged from 73 to 81 percent

LABORATORY PROCESSING

At the laboratory, fish were unwrapped and weighed to the nearest ounce for large fish and to the nearest 10 g for small fish, and measured to the nearest 1/4 inch (reported in cm) After wiping the slime coat from each fish with a paper towel, a skinless fillet from the left side was collected with a stainless steel fillet knife The fillets were individually weighed and then composited by species for either organics or metals analysis Because as much tissue as possible is required for analysis, the entire fillet from each fish was composited Thus composites are weighted towards larger fish Fillets came in contact only with the filleter's hands, the fillet knife and either fresh aluminum foil or fresh plastic depending on their analytical destination

Composite samples were delivered to the chemical laboratory where the fillets were blended into homogeneous composites Those composites for inorganics testing were placed in plastic containers and frozen Those composites for organics analysis were analyzed fresh

RADIOLOGICAL ANALYSIS

In addition to providing information on contaminants that could result from known historical emissions of radioactive materials from the Rocky Flats Plant, these analyses also would provide evidence of either a criticality accident or an operating nuclear reactor Each sample was analyzed for a variety of mixed fission and activation products by direct gamma spectrometric analysis This procedure is the same as that used in the routine surveillance of commercial nuclear power reactors (Colorado Department of Health 1989)

A 10-g aliquot of each composite was analyzed separately for plutonium-239+240 by actinide separation and alpha spectrometry according to CDH methods that have been used since 1970 Tissues were digested in hydrofluoric acid together with a plutonium-236 tracer, and the plutonium was eluted by ion exchange chromatography The plutonium was then electroplated on a stainless steel planchet and the plutonium-239+240 was measured by alpha spectrometry Any sample losses were corrected by measuring the recovery of the plutonium-236 tracer A duplicate analysis was conducted on the channel catfish composite as a quality assurance measure

For uranium analysis, 10-g of tissue was digested according to EPA method 3050 and diluted to 50 ml This was then analyzed by the CDH fluorometric method

ORGANICS ANALYSIS

Organochlorine and organophosphorus pesticide residues were extracted according to AOAC (AOAC 1984) Method 29 001 and, 29 012 - 29 015 Extracts were analyzed by gas chromatography using both electron capture detection and nitrogen-phosphorus detection Results were confirmed by gas chromatography/-mass spectrometry

METALS ANALYSIS

For chromium, beryllium, lead, cadmium and nickel, 5 0 grams of tissue was digested with nitric acid and hydrogen peroxide according to EPA method 3050 (U S. EPA 1986) Digestions were diluted to 50 ml and analyzed by atomic absorption spectrophotometry (AAS) by EPA methods 218 1, 210 1, 239 1, 213 1 and 249 1 (U S EPA 1979)

For mercury 0 5 g was analyzed by cold vapor AAS according to EPA method 245 1 (U S EPA 1979) For selenium, 10 g of each sample was dried and ashed at 600C° then diluted to 50 ml with 0 15% nitric acid A 25- ml aliquot of this solution was then analyzed fluorometrically according to the CDH method

A duplicate analysis for all these metals, mentioned above, was conducted on a separate aliquot of tissue from the channel catfish composite

RISK ASSESSMENT

In performing the risk assessment, the CDH evaluated the impacts of radionuclides and EPA Region VIII evaluated organic chemicals and metals

The dose response assessment for radiation was based on the U S Department of Energy's dose conversion factors (U S DOE 1988) For metals and organic chemicals, it was consistent with EPA guidelines (U S EPA 1989)

Because there were no detectable quantities of radionuclides in the fish samples, the typical case was calculated at the lower limit of detection for each of 22 radionuclides for which analyses were performed, to provide a very conservative estimate of potential risk This effective whole body radiation dose (based on individual organ radiation sensitivities) assumes that four ounces of fish would be consumed per week for 70 years This consumption rate is more than twice as conservative as that assumed by the majority of states in establishing fish and water ingestion criteria (U.S EPA August, 1989) The human health risk for this typical case dose was determined by summation of the doses for all radionuclides analyzed The collective dose in millirems was equated to health risk at a rate of 0 0002 cases (somatic and genetic) per rem (ICRP 1977)

The computed dose and associated health risk were compared with the National Council on Radiation Protection's Negligible Individual Risk Level (NCRP 1987) of 0 001 rem per year (or 0 070 rem per 70 years) with an associated health risk (somatic only) of 1 in 10,000,000 per year (or 7 0 in a 1,000,000 per 70 years) Details of these assessments are presented in Appendix B

The risk assessment for metals and organic chemicals was conducted by EPA The assumptions used to calculate exposures listed in Appendix C are consistent with those used in the risk assessment for radionuclides For non-carcinogenic compounds, the exposures were compared with the reference doses, found in the EPA Integrated Risk Information System (IRIS), which are the amounts of a chemical which can be ingested without an appreciable risk of deleterious effects during a lifetime In the case of carcinogenic compounds, the exposure was multiplied by the carcinogenic potency factor obtained from IRIS to estimate the upper limit of lifetime cancer risk

RESULTS AND DISCUSSION

In the following sections, findings of chemical and radiological analysis of the fillet composites and the calculated risk assessment are presented As described above, this initial screening project was restricted to composite sampling Because individual fillets were not analyzed, there are no estimates of the range or variance of the underlying population and thus no uncertainty analysis However, compositing unequal weights of fillets from individual fish provides an average weighted towards the larger fish This provides a worst-case analysis because the pollutants tend to accumulate in higher concentration in the larger fish

In addition, because of available time and resources for this initial screening effort, the study did not include a comparison of metals/pesticide residues in fish from other lakes in the region Monitoring of fish for contaminants is not routinely performed in Colorado Therefore, little comparative data were available Had such data been available, it would have been possible to determine whether the concentrations were normal or were atypical

RADIONUCLIDES

Concentrations of radionuclides, including uranium (all isotopes in natural abundance), plutonium-239+240, cesium-137 and 18 other gamma emitters (fission byproducts), were not present in detectable quantities in any of the species of fish that were analyzed (Table 2 and Appendix B) As previously mentioned, although no radionuclides were detected, the lower limits of detection, rather than zeros, were used in the risk evaluation The resulting estimate of risk

is probably higher than any actual risk that might result from Standley Lake fish consumption This method of calculation also served to ensure that the detection levels were low enough to identify any health impact if it existed

Analysis for tritium and radiostrontium was not performed However, the failure of other radionuclides to appear in detectable quantities provides sufficient reason to conclude that they would not be present in detectable quantities

The measurement sensitivity for gamma-emitting radionuclides in walleye, catfish and trout was superior to the surveillance requirements of the U S Nuclear Regulatory Commission for fish collected near commercial power reactors Because the amount of tissue in the smallmouth bass sample was small, the sensitivity of the measurements for that sample did not meet these same requirements Sensitivity for the plutonium analysis was considered to be very good for all species

The maximum 70-year committed effective dose equivalent (CEDE) for all radionuclides combined was estimated to be much less than 0 004 rem (CEDE rem) This is much less than the Negligible Individual Risk Level (NIRL) equivalent dose of 0 070 CEDE rem established by the National Council for Radiological Protection and Measurements The associated maximum 70-year (somatic and genetic) risk was estimated to be much less than 0 8 in 1,000,000 This estimate was less than the somatic risk level of 7 0 in 1,000,000 in 70 years calculated from the NIRL

ORGANIC CHEMICALS

Table 2 presents the results of only those organic chemicals found at detectable levels All of the priority pollutant organics with the exception of DDT (Dichloro-diphenyl-trichloroethane) and its metabolites DDE and DDD and malathion were not present in any detectable quantity Concentrations of DDT, DDE, and DDD in the trout, smallmouth bass and walleye ranged from 0 002 to 0 006 ug/g (wet weight basis) and ranged from 0 02 ug/g to 0 03 ug/g in the channel catfish These concentrations are below the FDA allowable tolerance levels which existed at the time that DDT was registered for use A trace of malathion was found only in the smallmouth bass composite, at a non-quantifiable level below 0 1 ug/g, but above the minimum detectable level of 0 01 ug/g

Because of its widespread historical use as a pesticide and its persistence in the environment, DDT and its metabolites DDE and DDD are ubiquitous and are detected in many foods in small amounts, including fish Based on levels found in the channel catfish, average weekly consumption of four ounces of catfish would result in a dose of 0 017 ug/kg/day which is well under the non-cancer

reference dose of 0 5 ug/kg/day (Appendix C) DDT is also classified as a probable human carcinogen and the upper limit of the lifetime cancer risk, assuming a weekly meal of catfish, would be 6 in 1,000,000 (Appendix C) To put this in perspective, in a group of 1,000 people who ate a weekly meal of channel catfish over a lifetime, an additional 006 cases of cancer would occur in those 1,000 people over what would be expected

The exposure to malathion, an organophosphate insecticide, from a weekly meal of four ounces of smallmouth bass would be 0 01 ug/kg/day, which is well below the acceptable reference dose of 20 ug/kg/day (Appendix C)

METALS

Table 2 lists the concentrations of metals found in the fish fillets expressed on a wet weight basis Only cadmium, mercury and selenium were detected

Cadmium concentrations were 0 48 ug/g in rainbow trout, 0 40 ug/g in the smallmouth bass, 0 26 ug/g in the walleye and less than 0 23 ug/g in the channel catfish The exposure to cadmium from an average weekly consumption of four ounces of rainbow trout would be 0 12 ug/kg/day, which is less than the reference dose of 1 ug/kg/day

Mercury was detected in all species and concentrations ranged from 0 06 ug/g in the rainbow trout to 0 21 ug/g in the smallmouth bass Assuming this mercury to be all methyl mercury, the specified routine consumption of smallmouth bass would result in an exposure of 0 05 ug/kg/day, which is below the reference dose of 0 3 ug/kg/day for methyl mercury

Selenium was found only in the smallmouth bass, at a concentration of 0 02 ug/g This would result in an exposure of 0 005 ug/kg/day, which is less than the reference dose of 3 ug/kg/day

The duplicate analysis of the channel catfish revealed only a difference in the mercury concentrations which were 0 09 ug/g and 0 14 ug/g Other metals were below the detection limit in both samples

POTENTIAL SOURCES OF CONTAMINANTS

This study did not attempt to determine the source of the pollutants detected in the fish However, based on water quality monitoring in the basin, likely sources are the immediate lake environment, and the watershed In addition, the majority of the trout in the lake were stocked, and this study did not include any separate examination that distinguished between recently stocked fish and other fish in the reservoir In the lake, fish accumulate pollutants through a combination of chemical-specific contaminants in food, water and sediment

The primary source of the pollutants is most likely the water inflow, most of which comes from other drainage basins Ninety-six percent of the inflow is water diverted from Clear Creek through the Farmers' Highline Canal and the Croke Canal Clear Creek contains pollutants from a variety of sources For example, in the past five years, it has received pollutants from municipal dischargers, industrial dischargers, mining activities and non-point sources These sources may have contributed pollutants to the water and sediment

To a lesser extent, the immediate watershed, including the Rocky Flats area, may be contributing pollutants However, of the contaminants found in the fish, none are unique to operations at the Rocky Flats Plant

CONCLUSION

Based on the results of the risk analysis of the fish fillets, using a conservative (i e , health protective) estimate of lifetime weekly consumption, consumption of an average amount of fish from Standley Lake does not present an appreciable health risk No non-cancer toxicological impacts were predicted With regard to DDT, DDE and DDD, there is an extremely small increased lifetime risk of cancer for people eating channel catfish from the lake However, because DDT and its metabolites are ubiquitous in the environment, the increased risk is not unique to Standley Lake

This initial screening study did not include the collection and analysis of fish samples from other Colorado lakes and reservoirs Therefore, no comparisons could be made As part of follow-up monitoring, multiple composites or individual fish samples from a variety of lakes should be analyzed so that statistical comparisons can be made

In addition, monitoring should be conducted at Standley Lake to verify the concentrations of mercury and cadmium in fish These two metals were at concentrations that, although not posing a significant risk, are near the reference doses and therefore warrant further assessment With this additional monitoring, the data and conclusions in this report could be confirmed

Acknowledgements

Several people from state and federal agencies contributed to this study Robert McConnell of the CDH Water Quality Control Division was responsible for the sampling design, collection and preparation of the fish for analysis, as well as preparation of a first draft of this report The CDH Laboratory Division, supervised by Dr Elizabeth Sexton and Howard Olson, and the Radiation Control Division performed the chemical analysis of the fish Albert Hazle of the CDH Rocky Flats Program Unit prepared the risk assessment for radionuclides and Dr Robert Benson of EPA Region VIII prepared the risk assessment for metals and organic compounds James Satterfield and Spencer Dumont of the Colorado Division of Wildlife participated in designing the study and collecting the fish Kathleen Bogert provided valuable assistance in the final preparation of this report Critical review and comment were provided by the following persons Paul Frohardt, Kay Kishline, Judy Bruch and Dr Norma Morin of the CDH Rocky Flats Program Unit, by Dr Karen Gottlieb and Judy Becher of the CDH Disease Control and Environmental Epidemiology Division, and by Robert Terry of the CDH Radiation Control Division

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Table 1 Whole fish lengths and weights and fillet weights for fish captured at Standley Lake June 28 and 29, 1989

Species	Type of Analysis	Whole fish Length (cm)	Whole fish Weight	Fillet weight (g)
Walleye	I	59	102 oz	450
	I	40	19 oz	66
	I	37	16 oz	82
	O	61	94 oz	390
	O	48	36 oz	180
	O	37	16 oz	73
Channel catfish	I	41	20 oz	70
	I	48	41 oz	145
	I	53	66 oz	290
	O	48	39 oz	79
	O	43	24 oz	41
	O	33	12 oz	22
Smallmouth bass	I	29	10 oz	44
	I	25	5 oz	24
	I	22	102 g	19
	O	29	350 g	49
	O	22	165 g	23
	O	21	135 g	22
Rainbow trout	I	31	8 oz	35
	I	27	6 oz	35
	I	27	185 g	36
	I	34	250 g	40
	I	30	230 g	45
	I	30	310 g	82
	O	31	220 g	35
	O	30	190 g	30
	O	28	230 g	39
	O	26	190 g	35

Type of analysis I = inorganic (wrapped in plastic)
O = organic (wrapped in aluminum foil)

Table 2 Concentration of pollutants in fish fillet (left side without skin) composites collected from Standley Lake on June 18 and 29, 1989 Concentrations are on a wet weight basis

Pollutant	Rainbow Trout (Composite)	Channel Catfish (Composite)	Channel Catfish (Duplicate Analysis)	Smallmouth Bass (Composite)	Walleye (Composite)
RADIONUCLIDES pCi/g					
plutonium 239+240	< 0 0002	< 0 0001	< 0 0003	< 0 0003	< 0 0002
cesium 137[A]	< 0 02	< 0 010	---	< 0 282	< 0 009
uranium (all isotopes)	< 0 01	< 0 01	< 0 01	< 0 01	< 0 01
ORGANIC CHEMICALS[B] - ug/g					
DDT	0 006	0 030	---	0 005	0 004
DDE	0 003	0 020	---	0 002	0 002
DDD	0 004	0 020	---	0 003	0 004
malathion [C]	< 0 01	< 0 01	---	0 040	< 0 01
fat extract (g)	0 12	0 24	---	0 09	0 26
METALS - ug/g					
beryllium	< 0 50	< 0 50	< 0 50	< 0 50	< 0 50
cadmium	0 48	< 0 23	< 0 23	0 40	0 26
chromium	< 0 99	< 0 99	< 0 99	< 0 99	< 0 99
lead	< 2 5	< 2 5	< 2 5	< 2 5	< 2 5
mercury	0 06	0 09	0 14	0 21	0 18
nickel	< 0 99	< 0 99	< 0 99	< 0 99	< 0 99
selenium	< 0 01	< 0 01	< 0 01	0 02	< 0 01
NO FISH PER COMPOSITE					
organics	4	3	---	3	3
metals & radionuclides	6	3	---	3	3

A All other fission byproducts are also less then detectable, and are tabulated separately in Appendix B

B Only those organics found at detectable levels are tabulated

C The minimum detectable level is 0 01 ug/g the practical quantitation limit is 0 1 ug/g

Suspected Contaminants for Analysis

Radionuclides

Plutonium - 239 and 240

Uranium

Cesium 137 (and 20 other gamma-emitting fission products)

Americium (not analyzed - may be calculated on the basis of maximum ingrowth in Rocky Flats grade plutonium)

Metals

Chromium

Selenium

Beryllium

Lead

Mercury (total)

Cadmium

Nickel

Organic Chemicals

Priority pollutants analysis including

Volatile organic chemicals

Chloroform

Acetone

Methylene chloride

Benzene

Semi-volatile organic chemicals

Phthalates

Pesticides

PCB

DOSE AND RISK FROM THE INGESTION OF FISH

SOURCE = STANDLEY LAKE (06/29/89)

	DOE REM/uCi CEDE *	picoCurie/gram tissue: WALLEYE PIKE	CATFISH	TROUT	BASS	TYPICAL CASE	70 YR DOSE (REM)	70 YR RISK
Pu-239+240	5.7	< 2e-4	< 2e-4	< 2e-4	< 3e-4	< 2e-4	< .0004706	< .0000001
URANIUM	.25	< .01	< .01	< .01	< .01	< .01	< .0010319	< .0000002
GAMMA ANALYSIS								
COUNT TIME (seconds)		75,000	75,000	75,000	175,000			
MASS COUNTED (grams)		536	459.	246.	65.2			
MN-54	.0027	< .009	< .011	< .021	< .29	< .009	< .0000108	< 2.006e-9
CO-58	.0035	< .009	< .011	< .021	< .297	< .009	< .0000138	< 2.660e-9
FE-59	.0066	< .024	< .026	< .051	< .715	< .024	< .0000654	< 1.308e-8
CO-60	.026	< .009	< .01	< .019	< .264	< .009	< .0000966	< 1.932e-8
ZN-65	.014	< .022	< .025	< .049	< .689	< .022	< .0001271	< 2.543e-8
ZR-95	.0034	< 007	< 019	< 036	< .536	< .007	< .0000098	< 1.965e-9
NB-95	.0022	< .006	< .011	< .021	< .308	< .006	< .0000054	< 1.090e-9
MO-99	.0044	< .007	< .009	< .02	< .446	< .007	< .0000127	< 2.543e-9
RU-103	.0027	< .006	< .007	< .013	< 266	< 006	< .0000067	< 1.337e-9
RU-106	.021	< .072	< .08	< .153	< 2 41	< .072	< .0006241	< .0000001
SB-125	.0026	< .014	< .016	< 03	< .706	< .014	< .0000158	< 3.005e-9
I-131	053	< .005	< .009	< .014	< .389	< .005	< .0001094	< 2.188e-8
TE-132	.0074	< .017	< .024	< .055	< 1.12	< .017	< .0000519	< 1.039e-8
CS-134	074	< 011	< .012	< .023	< .332	< .011	< .0003368	< .0000001
CS-136	.011	< .014	< .017	< .033	< .491	< .014	< .0000636	< 1.271e-8
CS-137	.05	< .009	< .01	< .02	< .282	< .009	< .0001857	< 3.715e-8
BA-140	.0004	< .018	< .022	< .045	< .863	< .018	< .0000624	< 1.248e-8
LA-140	.0077	< .01	< .012	< .025	< .386	< .01	< .0000318	< 6.357e-9
CE-144	.02	< .093	< .009	< .157	< 2.33	< .093	< .0007677	< .0000002
						'' MAXIMUM TOTAL '' =	<< .0040978	<< .0000008

CEDE * = Reference: Internal Dose Conversion Factors for Calculation of Dose to the Public
U.S. Department of Energy, Washington, DC, July 1988 (NTIS)
[CEDE = Committed Effective Dose Equivalent (all organs considered)]

NOTE: For equal tissue masses (gms) and counting times, the lower limits of detection will be the same, i.e., Walleye Pike (the most sensitive analysis) used as the TYPICAL CASE

70 YEAR DOSE(REM) = Conc. X REM/uCi X 1e-6 uCi/pCi X 1/4 #/meal X 1 meal/week X 52 weeks/year X 70 years
[70 year consumption using acute exposure ingestion equations and 50 year dose acquisition period]

70 YEAR RISK = (70 YEAR DOSE (CEDE REM)) X (0.0002 risk/CEDE REM)

0.0002 risk/CEDE REM = Ref.: International Commission on Radiological Protection #26, p12, para (60)
[includes both somatic (0.0001 risk/REM) and genetic risk (0.0001 risk/REM)]

The Negligible Individual Risk Level of the National Council on Radiation Protection and Measurements is equal to or less than, 0.070 CEDE REM in 70 years and a somatic risk level of 0.000007 in 70 years
[NCRP Report No. 91, Section 20, pp 43-45, June 1, 1987]

NOTE: Nothing in this data indicates an impact from the Rocky Flats Plant

09/01/89 AJH

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
999 18th STREET - SUITE 500
DENVER, COLORADO 80202-2405

Ref: 8WM-DW

MEMORANDUM

Date: November 29, 1989

To: Bob McConnell, Water Quality Division
Colorado Department of Health

From: Bob Benson, Toxicologist
Drinking Water Branch

Subject: Contaminants in fish from Standley Lake

I have reviewed the data on the fish collected from Standley Lake. Only the concentrations of DDT, DDE, DDD, malathion, cadmium, mercury, and selenium exceed the minimum detection levels. Malathion and selenium were detected in only one fish sample. In all cases consumption of a reasonable quantity of fish from Standley Lake results in exposure to the chemical [illegible] EPA's reference dose (RfD) for non-cancer toxicological effect for the chemical. Because EPA classifies DDT, DDE, and DDD as probable human carcinogens, consumers of fish from Standley Lake will have an increased lifetime risk of cancer. A quantitative risk assessment for DDT, DDE, and DDD shows that the upper limit of the lifetime risk of cancer is 6 in 1,000,000.

My conclusion is that consumption of a reasonable quantity of fish from Standley Lake does not present a significant health risk to the public. Because cadmium and mercury bioaccumulate in fish tissue, and because the exposures to these chemicals are close to the RfD's, additional monitoring of fish, water, and sediment for these chemicals is prudent. Additional monitoring would be especially prudent if contamination of the lake with cadmium and mercury is likely to continue.

Assumptions

I made the following assumptions:

1. a sportsfisherman and his family consume one meal of fish from Standley Lake per week,
2. the average serving size is 120 grams (about four ounces),
3. exposure continues for a lifetime,
4. the most highly contaminated species is consumed, and
5. the average body weight is 70 kg.

DDT, DDE, and DDD

DDT was previously one of the most widely used pesticides. DDE and DDD are degradation products of DDT. EPA has cancelled the uses of DDT. However, because of persistence in the environment, DDT, DDE, and DDD are often detected in food samples. The average concentration of these chemicals in meat, fish, and poultry in 1982 was 0.003 ug/gram. The Food and Drug Administration (FDA) has established an action level for fish in interstate commerce of 5 ug/gram. FDA's action level is based on the concept of an unavoidable contamination, rather than a quantitative risk assessment.

The total concentration of DDT, DDE, and DDD in catfish from Standley Lake is 0.07 ug/gram. The RfD for non-cancer effects is 0.5 ug/kg/day. The exposure to DDT, DDE, and DDD from a weekly meal of catfish is 0.017 ug/kg/day.

(120 g fish/meal x 1 meal/week x 1 week/7 days x 1/70 kg x 0.07 ug DDT, DDE, DDD/g fish)

DDT is known to cause liver tumors in experimental animals. On this basis EPA classifies DDT, DDE, and DDD as probable human carcinogens with a cancer slope factor of 0.34 $(mg/kg/day)^{-1}$. The upper limit of the lifetime cancer risk is 6 in 1,000,000.

$[0.34\ (mg/kg/day)^{-1} \times 0.017 \times 10^{-3}\ mg/kg/day]$

Malathion

Malathion is an organophosphate insecticide. The toxicity associated with the ingestion of malathion is inhibition of acetylcholinesterase, an enzyme involved in the transmission of nerve impulses. The concentration of malathion in the smallmouth bass is 0.04 ug/gram. The RfD for malathion is 20 ug/kg/day. The exposure to malathion from a weekly meal of smallmouth bass is 0.01 ug/kg/day.

(120 g fish/meal x 1 meal/week x 1 week/7 days x 1/70 kg x 0.04ug malathion/g fish)

Cadmium

Cadmium is a naturally occurring heavy metal. The toxicity associated with the ingestion of cadmium is kidney damage. Cadmium accumulates in the kidney and causes renal damage when the concentration of cadmium in the kidney exceeds 200 ug/g. Cadmium accumulates in aquatic and terrestrial organisms. Typical concentrations of cadmium in fish from non-polluted areas range from 0.001 to 0.1 ug/gram. The concentration of cadmium in

rainbow trout from Standley Lake is 0.48 ug/gram. The RfD for cadmium from food is 1 ug/kg/day. The exposure to cadmium from a weekly meal of rainbow trout is 0.12 ug/kg/day.

(120 g fish/meal x 1 meal/week x 1 week/7 days x 1/70 kg x 0.48 ug cadmium/g fish)

Mercury

Mercury is a naturally occurring heavy metal which bioaccumulates in fish as methyl mercury. The major exposure of people to methyl mercury is from fish. The toxicity associated with the ingestion of methyl mercury is damage to the nervous system. The average concentration of methyl mercury in most fish is less than 0.2 ug/gram. The concentration of mercury in smallmouth bass from Standley Lake is 0.21 ug/gram. The RfD for methyl mercury is 0.3 ug/kg/day. The exposure to mercury from a weekly meal of smallmouth bass is 0.05 ug/kg/day.

(120 g fish/meal x 1 meal/week x 1 week/7 days x 1/70 kg x 0.21 ug mercury/g fish)

Selenium

Selenium is a naturally occurring heavy metal which is an essential nutrient, but which is also toxic when excessive quantities are consumed. The amount necessary to maintain good nutritional status is 50-200 ug/day. The average diet contains 75-150 ug/day. Selenosis is observed when ingestion exceeds 3200 ug/day. The concentration of selenium in the smallmouth bass from Standley Lake is 0.02 ug/gram. The RfD for selenium is 3 ug/kg/day. The exposure to selenium from a weekly meal of smallmouth bass is 0.005 ug/kg/day.

(120 g fish/meal x 1 meal/week x 1 week/7 days x 1/70 kg x 0.02 ug selenium/g fish)

304923-B4

CONTROLLED AREA

HOLDING PONDS

HOLDING PONDS

903 PAD

IHSS 200

IHSS 202

IHSS 201

ROCKY FLATS BOUNDARY

DEPARTMENT OF ENERGY

Great Western Reservoir

Mower Reservoir

Upper Church Lake

Lower Church Lake

Standley Lake

Standley Lake County Park

Kelver Reservoir

Walnut Creek

Woman Creek

Spring Gulch

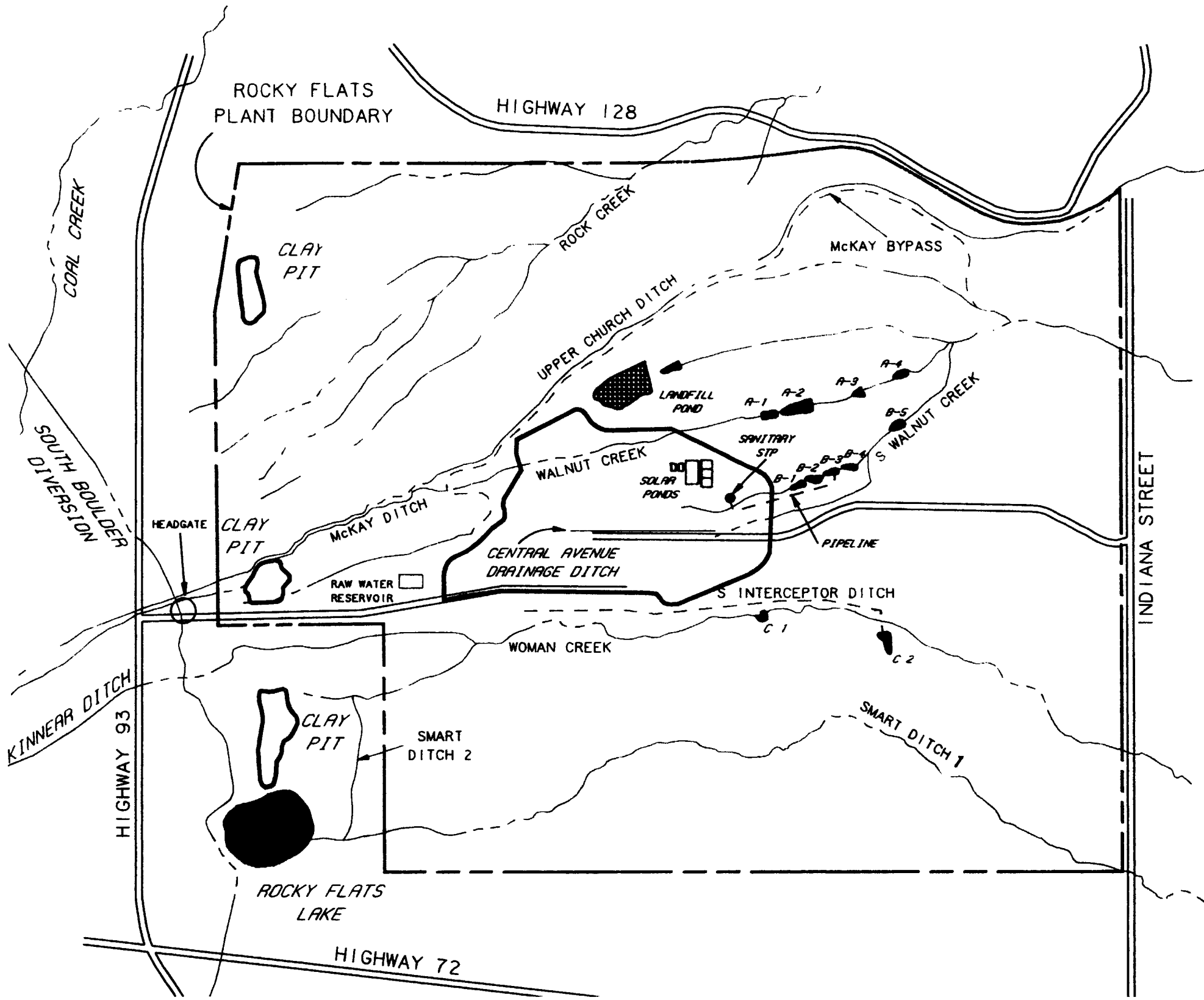
SCALE

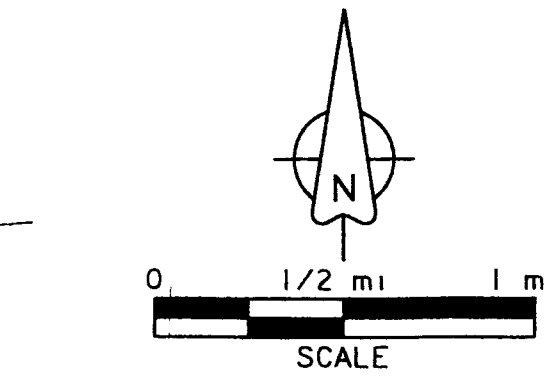
0 2000 4000 FEET

FIGURE 2-1

SITES 200-202 LOCATION MAP

DRAWN BY	KRONER 6-12-91	CHECKED BY	CJR 06 2 91	DRAWING NUMBER 3 23-B14
		APPROVED BY	CJR 06 12 91	





LEGEND

- WASTEWATER STORAGE
- STORMWATER STORAGE
- SURFACE WATER FEATURE

FIGURE 2 2

UPSTREAM AND ON SITE SURFACE WATER FEATURES

SOURCE DRAFT ROCKY FLATS SURFACE WATER MANAGEMENT PLAN MARCH 1991

DRAWN BY	KROMER 6-12-91	CHECKED BY	CJR 04 2 91	DRAWING NUMBER 304923-B15
		APPROVED BY	CJR 04 12 91	

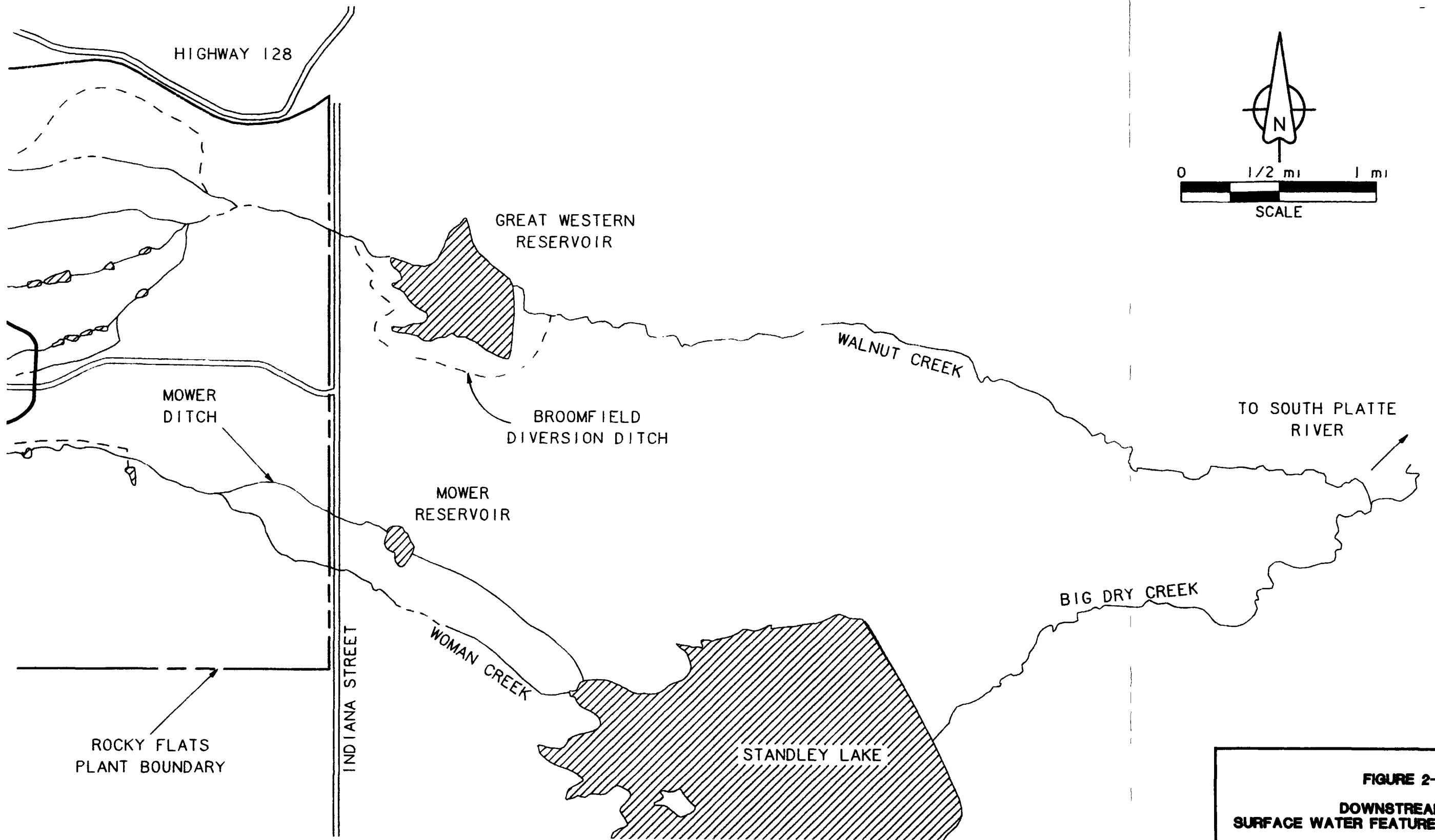


FIGURE 2-3

DOWNSTREAM SURFACE WATER FEATURES

SOURCE DRAFT ROCKY FLATS SURFACE WATER MANAGEMENT PLAN MARCH 1991

492381

DRAWN BY	RITA HYNA	CHECKED BY	CJR	6 12 91	DRAWING NUMBER
	6/5/91	APPROVED BY	CJR	6 12 91	304923-B13

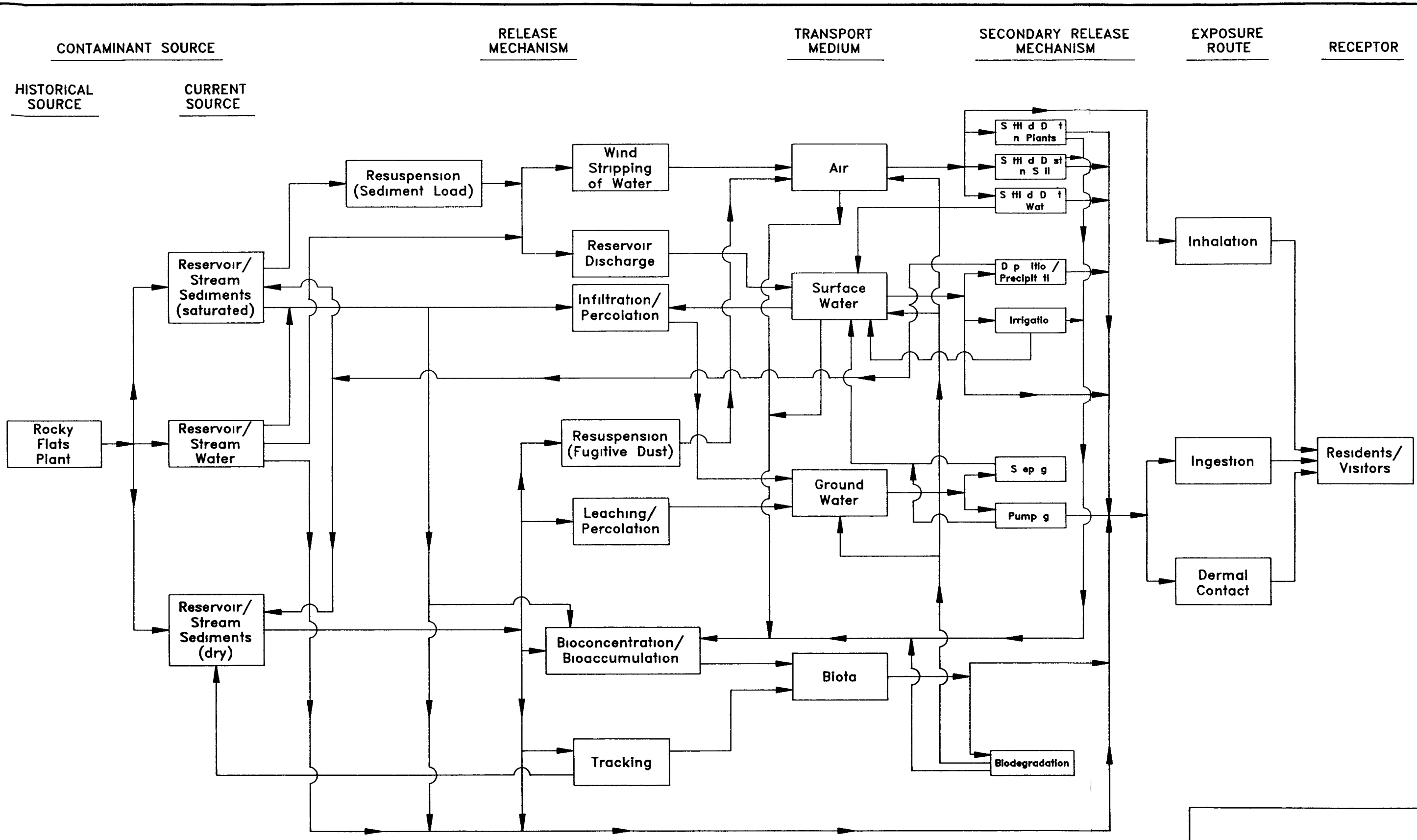


FIGURE 3–2

GENERAL CONCEPTUAL MODEL FOR SITES 200–202